O.F.I. OCCASIONAL PAPERS

O.F.I. OCCASIONAL PAPERS

No. 45

UTILIZATION OF *PINUS PATULA*: AN ANNOTATED BIBLIOGRAPHY

J.A. WRIGHT

1994

OXFORD FORESTRY INSTITUTE
Department of Plant Sciences
UNIVERSITY OF OXFORD

O.F.I. OCCASIONAL PAPERS

No. 45

UTILIZATION OF *PINUS PATULA*: AN ANNOTATED BIBLIOGRAPHY

J.A. WRIGHT

1994

ISBN 0 85074 130 0
ISSN 0269-5790

Oxford Forestry Institute
Department of Plant Sciences
University of Oxford

UTILIZATION OF *PINUS PATULA*: AN ANNOTATED BIBLIOGRAPHY

J.A. Wright
Smurfit Carton de Colombia
Division Forestal
Cali, Colombia

1994

Here we will gratify our curious reader with as curious an account of the comparative strength, and fortitude of the several usual sorts of timber, as upon any suggestions previous to this work, it was several times experimented...

Sylva: Or a Discourse of Forest Trees & the Propagation of Timber. John Evelyn F.R.S.
First published in 1670.

Table of Contents

Page

Acknowledgements iii

Foreword iv

1. Introduction 1

2. Chemical Constituents 3
    - 2.1 Resin 3
    - 2.2 Wood 4
    - 2.3 Bark 6
    - 2.4 Needles 6

3. Wood Density 6
    - 3.1 Genetic Control of Wood Density and Associated Traits 6
    - 3.2 Site and Management Effects 8
    - 3.3 Age Effects 11

4. Tracheid and other Fibre Dimensions 12

5. Wood and Tree Defects 16
    - 5.1 Spiral Grain 16
    - 5.2 Compression Wood 17
    - 5.3 Nodal Swelling 18
    - 5.4 Branching and Pruning 18

6. Bark 19

7. Biomass 20

8. Charcoal and Fuelwood 22

9. Wood Degradation and Preservation 23
    - 9.1 Untreated Wood 23
    - 9.2 Treated Wood 24

10. Reconstituted Wood Products 27
    - 10.1 Wood Adhesives 27
    - 10.2 Particle Board and Related Products 27

11. Poles and Posts 28

12. Sawmill Products 29
    - 12.1 Recovery 29
    - 12.2 Drying and Shrinkage 30
    - 12.3 Lumber Strength, Quality and Uses 32
    - 12.4 Grading 36

13. Veneer and Plywood 36

14. Pulp and Paper-making Characteristics 37
    - 14.1 Chemical and Semi-Chemical Processes 37
    - 14.2 Mechanical Pulp and Paper-making 42

15. Conclusions and Recommendations 43

References 46

Acknowledgements

The author would like to thank Smurfit Carton de Colombia for the opportunity to write this Annotated Bibliography. Advances in forest management and utilization will only be possible with implementation of appropriate research findings; the willingness of Smurfit Carton de Colombia to fund the present work is yet again an indication of their serious intent to manage and utilize their plantation investment.

Over the course of three years during which the documents were obtained, numerous researchers and librarians assisted by sending requested articles. Their effort to share technology in printed form is kindly acknowledged. At the Oxford Forestry Institute I would like to thank the library staff for their assistance in locating many of the documents included in the text. I must give a special thanks to Drs. Jeff Burley and Richard Barnes as well as Mr. Bob Plumptre and Mr. Ted Palmer for kindly reviewing and commenting on this document. Gillian Petrokofsky of CAB International suggested required changes in the References. Dr. Peter Kanowski made numerous reviews of previous manuscripts and his comments and suggestions greatly improved the final version. The thorough review and comments of Dr. Geoff Elliott are also acknowledged. Miss Liz Pearce prepared the final manuscript.

As always, the support, tolerance and respect for my self indulgence in this endeavour has come from Lisa, Delina, Sarah and William. It is to the four of them that this work is dedicated.

Foreword

Forestry is a long-term enterprise and, within the lifetime of an individual forester or a typical forest rotation, issues and favoured activities change, often in a cyclic fashion. In the period 1950 - 1980 there was a worldwide interest in the establishment and improvement of industrial plantations, particularly with exotic conifers, including tropical species, for both timber and paper. Throughout the 1980s there was a trend of political and socioeconomic opinion against industrial forestry and especially against the use of exotic species. Donor agencies, non-governmental agencies and many individual scientists preferred to concentrate on multipurpose trees for rural development and on the conservation of indigenous forests.

Nevertheless the demand for industrial forest products has not gone away; indeed, it has increased in parallel with increasing human population size and cultural requirements. In many countries, including several in the tropics, there is a resurgence of interest and investment in plantation forestry and wood products. It is clearly desirable for them to have access to the results of earlier work in order to reduce unnecessary duplication of research and to speed the processes of development.

The Oxford Forestry Institute Library and Information Service is one of the world's major deposit libraries for forestry and related literature. Members of OFI staff and students have for many years worked on the wood properties of tropical plantation species. Jeff Wright was one of these and subsequently worked on the same topics in South Africa before joining Carton de Colombia in Cali, Colombia. In spending a period of sabbatical leave in the Institute he was able to bring together the published and unpublished information and experiences of many workers and institutions in general and *Pinus patula* in particular. This Occasional Paper should act as a valuable source reference to the properties and uses of the species and to the interactions between anatomical and utilization properties as affected by environment, silviculture and tree breeding.

Dr Jeffery Burley
Director

1. Introduction

Pinus patula Schiede & Deppe in Schlectendal & Chamisso is the most intensively utilized conifer in the tropics and sub-tropics, where it is widely planted as an exotic. The species is indigenous to Mexico at altitudes 1500 to 3100 m and at latitudes 16°N to 24°N (Dvorak and Donahue, 1992) with mean annual precipitation of 600 to 2500 mm (Eguiluz, 1988). Within the native range it attains a height of 30 to 35 m with diameters of 50 to 90 cm (Perry, 1991). The botanic exploration of *P. patula* in Mexico has been reviewed by Standley (1926) and Loock (1977). Common names for the species in Mexico are pino colorado, ocote colorado, ocote macho and pino xalocote (Paz and Olvera, 1981).

The forest area of the species in Mexico has been declining due to land conversion to other agricultural use (Vela Galvez, 1976), accentuated by the presence of uncontrolled annual fires which prevent natural regeneration from developing (Sanchez Mejorada and Huguet, 1959) and also reduce growth rates in natural stands (Aguirre-Bravo and Smith, 1986). In one of the few silvicultural reports on native stands, Castanos (1962) indicated that the site index for *P. patula* in Oaxaca increased with an increase in soil depth and with a decrease in elevation.

In Mexico, *P. patula* has been planted for protection of watershed areas as well as for conservation and restoration of degraded soils (Patino and Kageyama, 1991). Vela Galvez (1980) believed that there was great potential for plantations of *P. patula* in Mexico; his contention was supported by Sanchez Mejorada and Huguet (1959), who documented results for plantations established from bare root stock in 1920 in the Desierto de los Leones, north of Mexico City. These plantations were growing at 10.5 cubic metres per hectare per annum at age 38 years.

P. patula timber in Mexico is utilized in light construction, carpentry and parquetry as well as for fuelwood (Borota, 1991; Cevallos and Carmona, 1981; Quinones, 1974). In spite of the lack of accurate data, the importance of the species for fuelwood should be highlighted, since twenty million people in Mexico rely on wood as fuel, mainly for cooking (Evans, 1984). *P. patula* is also frequently used as an ornamental tree in Mexico (Campos, 1990). Cattle grazing under *P. patula* stands is feasible although grazing is said to reduce growth rates in natural stands in Mexico (Aguirre-Bravo and Smith, 1986).

In spite of its relatively minor importance in Mexico, *P. patula* is of major importance in the southern hemisphere (Record and Hess, 1974), due to its good growth and wide adaptability (Zobel, 1970). Birks and Barnes (1991) estimated that up to one million hectares are presently planted to *P. patula*, while Borota (1991) gives the figure of 500,000 hectares in Africa alone. Growth rates and/or silvicultural regimes have been described for the species in South Africa (Poynton, 1957, 1979), Angola (Lopes de Silva, 1965), Cameroun (Anon., 1966), India (Pande, 1982) and Zimbabwe (Barrett and Mullin, 1968). The success of *P. patula* in plantation culture has been developed by determining appropriate sites and silvicultural methods (Wormald, 1975). However, a current review of the climatic conditions to which the species is adapted worldwide is long overdue.

Exotic plantations have been established for site protection or restoration and for wood production. The ability of these plantations to sequester CO_2 gas must now also be seen as a utilization characteristic. Streets (1962) described the use of *P. patula* as an exotic in the British Commonwealth countries of Australia, Nigeria, Sri Lanka, Fiji, Jamaica, Kenya and

New Zealand. Potential uses in these and other countries include: barn tiers on tobacco farms (Zimbabwe - Barrett and Mullin, 1968); control of soil erosion (Madagascar - Anon., 1988; Ecuador - Galloway, 1987; Nepal - Thapa, 1987; Malawi - Palmer and Gibbs, 1974); match boxes (Uganda - Tack, 1969); general construction and pulp (Uganda - Bryce, 1967; Madagascar - Gueneau, 1971); boxes and internal joinery (Tanzania - Anon., 1978); shade for coffee and fruit trees (Colombia - pers. obs.). *P. patula* from Uganda was said to give unacceptable results for turning (Anon., 1968).

One interesting use of *P. patula* in southern Africa is as the host for an edible mushroom, *Boletus edulis* Bull. ex Fr. This mushroom is harvested in plantations, dried and exported to Europe. The importance of this ectotrophic mycorrhizae for the growth of *P. patula* was discussed by Marais and Kotze (1975, 1977).

Pioneering work in South Africa by Craib, Turnbull and others on the effects of tree growth on lumber quality in *P. patula* were the precursor to the development of import substitution and export opportunities for lumber from southern Africa. As growth rates have been increased and as more accurate methods of lumber testing are now available, it is surprising that there are not more recent reports in the literature that would correlate present growth rate(s) with lumber quality.

Previous reviews of *P. patula* have considered experiences in forestry or wood utilization (Plumptre, 1978; Wormald, 1975; FAO, 1973). Poynton (1957, 1979) has given a history of the use of *P. patula* in southern Africa while Kalish (1977) discussed the particular raw material prospects of *P. patula* in South Africa.

The objective of this work is to provide a synopsis of the published and unpublished scientific literature regarding utilization of *P. patula*. For those organizations with plantations of the species, this compendium will provide a reference for identifying potential uses. The prevailing use of *P. patula* for paper production possibly reflects, in part, the lack of investment into research, development and marketing of other products.

The reader is advised to determine local parameters such as supply of wood, technological skill and product demand before attempting to manufacture any of the products listed in this book. Products will certainly differ due to the environment in which the trees are grown, age of wood, skill in processing and the vagaries of the consumer. de Villiers (1972) stated that the greatest source of unreliability in wood of *P. patula* was the variation between trees; to this must be added variation due to all other factors (Zobel and van Buijtenen, 1989).

The author has intentionally not compared the wood properties of *P. patula* to those of other species. In many cases the references do present comparable data for other species. Where practicable the author has converted units expressed in Imperial measure to metric. Where this could lead to confusion, the author has not made the conversion.

This book has three parts: Chapters 2 to 5 describe the general characteristics which will have an effect on utilization. The actual utilization of the species is covered in Chapters 6 to 12. The third part of the book, Chapter 12, contains conclusions and recommendations. Each chapter begins with general information about variation and concludes with a discussion of consequences for end uses.

2. Chemical Constituents

2.1 Resin

Resin can be a defect or an economic opportunity in most pine species. For painting or other forms of wood treatment, an excess of resin is very undesirable. However, resin tapping has been conducted for centuries on various species of the genus *Pinus* and this is a valuable source of income and employment in countries such as Brazil and Zimbabwe.

In a study of the resin of 30 year old trees of *P. patula* at the Institute of Forest Genetics, Placerville, California, the turpentine yield was only 15% of the weight of the resin due to volatization under warm, dry conditions (Mirov, 1961). The physical characteristics of the turpentine were a density of 859 kg/m^3 with an index of refraction of 1.4885 and a specific rotation of -5.24^0. The chemical constituents of resin from a number of other sites are presented in Table 1; beta-phellandrene was the main constituent of resin at all locations and ages evaluated.

Resin pockets have been noted in *P. patula* from Queensland (Eccles *et al.*, 1975). This condition was probably due to moisture stress during periods of terminal growth. There was no correlation between size or number of resin pockets and tree growth rate. Wind damage in *P. patula* from Natal were found to have compression breaks that were resin infiltrated (Anon., 1971). The finishing properties of the wood could be affected by resin pockets, especially those close to knots (Anon., 1968). Wounds on *P. patula* from Tanzania were found to contain 48% of resin by weight (Kibuku *et al.*, 1972).

Donald (1982) found that paraquat injection into 30 year old *P. patula* increased oleoresin yield by 1.627 tons per hectare. The paraquat concentration used was 4% and it was suggested to make the injection one year prior to clearfelling. Turpentine yield was 12.1% of the weight of the resin in *P. patula* from Brazil (Assumpcao and Jordao, 1983). The non-turpentine fraction of the resin contained abietico (50.1%), dehidroabietico (15.0%) and others. Garrido *et al.* (1983) reported the resin yield of *P. patula* in Brazil at 411 g/tree/year. Trees with a diameter of 16 cm and an age of ten years gave a resin yield of 430 g per tree per annum in the state of Sao Paulo, Brazil (Gurgel Garrido and Garrido, 1988). Data presented by IPEF (1978) gave a resin yield of 1.78 kg/tree/year from *P. patula* in Sao Paulo state. However, the cost of extraction from *P. patula* was double that of other pine species due to the relatively low yields per tree.

Coppen (1991) and Coppen *et al.* (1988) reported on resin and turpentine quality in *P. patula*. They concluded that the species gave both poor yields and poor quality, and a similar conclusion has been reported in India (Panda and Panda, 1986). Annual production of pine resin in Mexico was estimated to be 30,000 tons in 1957 (Mirov, 1957). For Mexico, *P. patula* is not one of the major species tapped for resin (Tapia, 1986).

It seems that, for *P. patula*, the only defect arising from resin was in damaged trees. From an economic standpoint, there can be little doubt that the quantity of resin produced by *P. patula* is not sufficient to justify resin tapping. However, this low resin content is very desirable for certain manufactured products such as mechanical pulp and paper.

Table 1. Chemical constituents of resin (% weight basis) for *P. patula* from various locations. The constituents are alpha-pinene (A), beta-pinene (BP), beta-phellandrene (BL), longifolene (L), methyl chavicol (M) and delta-carene (D).

Reference	Location	Age (yrs)	Constituents
Assumpcao and Jordao, 1983	Brazil	-	BL 67.6, BP 3.8, A 16.1
Lockhart, 1990	Mexico	-	BL 70.0, L 10.0, A 10.0
Mirov, 1961	California	30	BL 80.0, L 10.0, A 5.0, M 5.0
Squillace and Perry, 1992	Mexico	-	BL 77.0, L 9.0, A 8.0
Williams and Bannister, 1962	New Zealand	-	BL 82.5, A 6.0, D5.0

2.2 Wood

The chemical constituents of wood will determine the cost and benefit of further processing, whether for utilization as charcoal, pulp, lumber or treated wood. The quantity of water in the wood is one of the primary components at the time of felling. Stohr (1980) sampled *P. patula* in South Africa and found the moisture content from wood of 14 year old trees to be 162.3% while for 21 year old trees the value was 166.0%. For trees of both ages, the moisture content was greater higher up the stem. Scott (1935) gave the normal moisture content of logs of *P. patula* in South Africa to be 200%. Ladrach (1985) reported that wood of *P. patula* had lost 52.2% of the initial water content following 180 days of storage in log form in Cali, Colombia. Wood from younger trees or from trees growing at higher altitude in Colombia had a higher content of water (Ladrach, 1984). Further data for the chemical constituents of wood are given in Table 2.

The wood of *P. patula* has been described as non-resinous in South Africa (Scott, 1953; Grut, 1965) and Madagascar (Anon., 1959a). Heartwood is normally not present in *P. patula* under the short rotation plantation forestry. However, Cummins (1972) has indicated a modified azo-dye reaction test for heartwood determination in the species. Ringo and Klem (1980) found that 25 year old *P. patula* from Sao Hill, Tanzania (altitude 1,500-2,000 m, 1,300 mm rainfall per annum), contained insignificant amounts (< 0.7%) of heartwood.

The solubility of wood will vary with the chemical compound used. Cittadani (1942) gave the figures for South African *P. patula* as 16.8% for water soluble compounds and 6.7% for sodium hydroxide soluble compounds. Uprichard (1970) found that, for five trees of *P. patula* at age 28 years grown in New Zealand, the methanol extractives decreased from the pith to the bark (3.8% for growth rings 1-5 versus 2.3% for growth rings 16-20). Trees of *P. patula* from the Vipyha plateau, Malawi, were assessed at ages 12 to 16 years for chemical constituents of the wood (Palmer and Gibbs, 1974). The 1% caustic soda solubility was 12.0% while alcohol-benzene solubility was 1.7%.

Table 2. Chemical constituents of wood (% weight basis) for *P. patula* from various locations. The constituents are cellulose (C), alpha-cellulose (AC), holocellulose (HC), hemicellulose (HEC), lignin (L), extractives (E), resin (R), pentosans (P) and ash (A).

Reference	Location	Age (yrs)	Constituent	Comments
Anon., 1934	Zimbabwe	-	C 52.5, L 27.6	
Anon., 1959a	New Zealand	37 16	R 0.6 R 1.7	
Anon., 1962	Kenya	15 7	C 42.9, E 0.92 C 40.6, E 1.58	
Cittadani, 1942	South Africa	-	C&P 45.9, L 30.0, A 0.6	
Escobar and Uribe, 1970	Colombia	-	C 57.50, HC 70.20, HEC 13.42, L 29.08	
Gonin, 1973	South Africa	40 40	C 48.1, L 25.5 C 44.3, L 26.9	bottom log top log
Howland and Patterson, 1971	Malawi	25	R 0.9	
Moorthy *et al.*, 1977	Kenya	-	L 28.4	
Palmer and Gibbs, 1974	Malawi	16	HC 61.6 AC 41.7	
Palmer *et al.*, 1984	Tanzania	14 6	HC 65.8, AC 43.0, L 28.6 HC 64.0, AC 40.1, L 29.3	
Orman, 1952	New Zealand	37	R 0.8	
Robertson, 1991	South Africa	17	L 28.0, E 3.1	
Tissot, 1968	Madagascar	-	C 50.8, L 28.4 P 8.6, A 0.28	
Tissot, 1968	Swaziland	-	C 53.6, L 28.7 P 9.2, A 0.27	
Uprichard, 1970	New Zealand	28 28	C 48.0, L 29.8, P 6.8 C 53.4, L 28.4, P 6.7	rings 1-5 rings 16-20

Schonau *et al.* (1981) evaluated the feasibility of alcohol production from *P. patula* wood in South Africa. In the proximate analysis, the components on an oven-dry basis were ash (0.39%), volatile matter (84.54%) and fixed carbon (15.07%). The ultimate analysis showed the wood to be comprised of carbon (51.27%), oxygen (41.84%), hydrogen (6.17%), ash (0.39%), nitrogen (0.30%) and sulphur (0.04%). The syngas yield was 0.71 to 0.67 m^3/kg dry wood. The methanol yield was 0.32 to 0.34 kg/kg dry wood. Low timber moisture content was essential in the production process.

Wayman and Parekh (1987) state that *P. patula* wood contains 730 kg of wood sugars per ton of wood (dry weight basis). Of the total, 606 kg are monomeric hexoses. Following treatment with sulphuric acid and inoculation with yeast an ethanol concentration of 1.41 g per 5 g of pine wood was realized. Ethanol production from *P. patula* wood was certainly feasible though the economics will vary depending on other available energy resources.

The wood of *P. patula* contains very little resin and heartwood for the ages specified, which are generally less than 40 years of age. There would appear to be more cellulose in mature wood than in juvenile wood (Table 2) which would be important from a pulping standpoint. The comparison of cellulose levels is made more difficult due to the different types of cellulose (alpha-, hemi- and holo-) that are reported. The quantity of lignin in the wood at 25% to 30% is normal for young pines.

2.3 Bark

Psotta (1979) evaluated the composition of bark from *P. patula* in South Africa. Lignin (30.5%) and phenolic acids (21.2%) were the most abundant compounds. The extractives (20.8%) were made up of tannins and fatty acids. The holocellulose (25%) had short fibres which would discourage use as in paper-making. The chemical analysis of *P. patula* bark was reported by Vitalis-Brun *et al.* (1990) for trees aged 15 to 16 years from Fanalamanga, Madagascar. The bark was 58.3% lignin, 13.9% cellulose, 7.0% pentosans, 6.3% extractives (water soluble), 8.0% extractives (alcohol-benzene) and 0.5% ash. A tannin yield of 6.5% was lower than that reported for the other pines evaluated.

Pizzi (1982) describes a bark tannin derived from *P. patula* in South Africa. When combined with other chemicals (polymeric diisocyanate or paraformaldehyde), an adhesive for reconstituted wood products was formed.

2.4 Needles

The nutrient levels for a number of elements in live needles of *P. patula* from Swaziland were reported (Morris, 1993) as nitrogen (1.55%), phosphorous (0.14%), potassium (0.83%), calcium (0.30%) and magnesium (0.18%).

3. Wood Density

The most important characteristic of a tree for most aspects of utilization is wood density although there will be some disagreement as to the magnitude of this importance. Wood density can easily be determined using a pilodyn or increment borer and thus large sample sizes can be obtained. The variation of wood density with site, age, position in the tree and genotype should be important for any organization with plantations of *P. patula.*

3.1 Genetic Control of Wood Density and Associated Traits

In order to select and breed trees for improved wood density, the genetic components of variation must be determined. The relationship between wood density and associated traits such as fibre length, latewood percentage, volume growth or dry-weight yield is also important. Estimates of heritabilities and genetic correlations will be essential in predicting likely gains from a tree breeding programme for improved wood density.

Breeding of *P. patula* for the improvement of sawtimber in South Africa began in 1958 (van der Sijde and Denison, 1967). Of the timber properties evaluated, spiral grain was the most important, followed by fibre length and wood density. At one time the main demand of softwood timber in South Africa was for construction use (de Villiers *et al.*, 1961). Paterson (1966a,b) estimated that tree breeding followed by the use of seed-orchard derived progenies would reduce stem defects by 5% to 25% and increase uniformity in almost all characteristics. Paterson (1969a) determined that, in Malawi, the total gain from tree improvement would be 60%. This would result from increased volume yield and higher sawn lumber recovery.

Selection of *P. patula* in Kenya for seed orchard establishment was conducted by Paterson (1969b). Wood cores were taken from each select tree as well as from five trees growing in close proximity and comparisons, based on a heritability of 50%, were estimated for their progeny. A reduction in latewood percentage of 6% to 4% over rotations of 20 and 30 years respectively was predicted. For corresponding rotation ages, the predicted reduction in wood density was 4% to 2.5%, for fibre length 3.7% to 1.5% and for grain angle 10% to 2%. This reduction in grain angle would be very beneficial for lumber utilization. The above information should be seen in a context of predicted improvements in volume yields of 25% to 60%, which would correspond to 50% to 80% in value. Progeny from the very best plus trees were projected to have 100% more volume than the average of the population (Paterson, 1967).

Gonin (1973) suggested that a tree breeding programme should consider the improvement of latewood percentage, because of the importance of latewood percentage in determining wood density. Burley (1967; 1973) stressed the importance of uniformity within individual trees of *P. patula* in a tree breeding programme; more latewood will increase the variability within a stem.

In two progeny trials of *P. patula* in Colombia assessed at seven years (Ladrach, 1987; Ladrach and Lambeth, 1991), families did not differ significantly in wood density. Mean values of wood density for seedlots from South Africa (344 kg/m^3) and Colombia (342 kg/m^3) were equivalent.

A genetic improvement programme for *P. patula* in Zimbabwe commenced in 1958 (Barnes *et al.*, 1992). The most thorough study of the genetic control on wood density in *P. patula* was undertaken in Zimbabwe, on 16 trials located at six sites (Birks and Barnes, 1991). The individual tree heritability for wood density was 0.35 with high juvenile-mature correlations. Wood density was found to be under strong general combining ability and to be slightly negatively correlated with volume. The authors cautioned that selection for density alone would be likely to lead to a reduction in volume growth.

However, in eight year old trials of *P. patula* in Zimbabwe, Barnes *et al.* (1992) found that wood density varied independently of stem volume, and that genotype environment interaction was absent. There was a high negative correlation between branch number and wood density. Family heritabilities of wood density at the two sites investigated were 0.59 and 0.74.

In one of the few reports of provenance differences for wood density, Barnes and Mullin (1984) stated that the trait was under a certain amount of genetic control. At six sites in Zimbabwe, the local seed orchard source was ranked the lowest for wood density. A positive correlation ($r = 0.63$) was noted between wood density and the number of rain days, while the correlation between wood density and volume was not significant ($r = - 0.19$).

One of the most important methods for controlling wood density is by selection and breeding. However, very few tree breeding programmes with *P. patula* include this trait because there is insufficient evidence to identify the wood density that will be important for products that will only be manufactured in 15 to 40 years time. The lack of agreement between researchers and managers on an ideal wood density has resulted in very little improvement in this trait though the required genetic parameters are known. Managers should be better able to specify the density range for wood that will enter their processing facilities. Researchers have not seemed willing to publish realized genetic and phenotypic gains in terms of wood density and other wood traits; this should be attempted in countries with more advanced breeding programmes.

3.2 Site and Management Effects

For plantations, both site and management will affect wood density. This will be due to rainfall distribution, temperature, spacing, thinning and fertilization, amongst others. In many cases, knowledge of these factors can be used to produce improved or more uniform wood density. The lack of knowledge concerning site and management effects could lead to production of wood that is not acceptable for the end use anticipated at the time of plantation establishment.

The density of actual wood substance is about 1,560 kg/m^3. Differences in wood density therefore result from differences in lumen width, cell wall thickness, lignin and resin content as well as the presence of compression wood. Moisture content determination is especially important when deriving the density of wood (Huy, 1985). A total of 30 trees of *P. patula* with a minimum diameter of 22 cm were selected in Piedras Blancas, Antioquia, Colombia (Anon., 1980). Wood density in the green condition was 960 kg/m^3 with a coefficient of variation of 9.8%. The air dry wood density was 520 kg/m^3 with a coefficient of variation of 22.4%. This large difference in coefficient of variation would be due to the variable nature with which water is removed in the drying of wood from different trees.

Fry (1957) concluded that earlywood and latewood were similar in density for *P. patula* from Kenya and thus concluded that the percentage latewood has little effect on wood density. Fry and Chalk (1957) noted that wood of *P. patula* from Kenya had latewood divided by a narrow band of earlywood. This is due to the period of two distinct wet and dry periods during the year. They reported that earlywood density was 368 kg/m^3 compared to 469 kg/m^3 for latewood, thus placing in some question the earlier statement of Fry (1957). Wood density was found not to vary significantly with cardinal directions in 27 year old trees of *P. patula* grown in Sao Hill, Tanzania (Ringo and Klem, 1986).

In one of the earliest reports on site effects, Turnbull (1938) indicated that earlywood formation depended on nutrients accumulated during the previous growing season while latewood was controlled by current climatic conditions. This theory was based on *P. patula* growing under South African conditions. Turnbull (1941) also mentioned the "amazing regional variations in density and strength that characterize so important a South African timber crop, as, for instance, *Pinus patula*". The wood density values reported over a wide range of climatic and growth conditions are summarized in Table 3.

Table 3. Wood density of *P. patula* from various locations.

Reference	Location	Age (yrs)	Density (kg/m^3)	Comments
ring basis				
Burley, 1973	Malawi	-	360 540	ring 4 ring 16
Ringo and Klem, 1989	Tanzania	-	353 546	ring 2 ring 20
Shutz, 1989	South Africa	38	353 474	rings 1-8 rings 23-30
Skolmen, 1963	Hawaii	-	357 438	rings 1-12 rings 18-30
Tobon, 1987	Colombia	-	419 488	ring 10 ring 20
Uprichard, 1970	New Zealand	28	330 480	rings 1-5 rings 16-20
Zobel, 1965	Mexico	-	390 470	rings 1-10 rings 31-40
juvenile/mature wood				
Ladrach, 1975	Colombia	-	519 393	mature wood juvenile wood
Lema *et al.*, 1978	Malawi	-	538 353	mature wood juvenile wood
Ringo, 1985a, b	Tanzania	-	464 361	mature wood juvenile wood
other				
Adlard *et al.*, 1979	Malawi	4-18	454	
Amaral *et al.*, 1977	Brazil	14	473 342	30 cm height 16.0 m height
Correa, 1988	Colombia	13 20	389 422	
Durand, 1983	Madagascar	15	330 383	fertile site less fertile site
Ferreira *et al.*, 1978	Brazil	6 14	337 404	
Guth, 1970	Argentina	7	321	
Ladrach, 1983	Colombia	7 10	312 462	
Lema *et al.*, 1978	Tanzania	-	408 464	lower rainfall higher rainfall
Moreschi *et al.*, 1977	Brazil	-	322	
Morris, 1982a	Swaziland	18 30	410 432	
Patterson, 1968a, b	Kenya	5 20	356 453	
Quinones, 1974	Mexico	- - -	586 595 707	Pueblo, Mexico Hidalgo, Mexico Veracruz, Mexico
Turnbull, 1947a, b	South Africa	-	537 448	0.3 m height 16.3 m height

Turnbull and du Plessis (1946) commented that wood density was independent of rate of growth (ring width) in *P. patula*. Then as now there was concern that fast tree growth will result in wood of lower density. Suppressed trees were lower in wood density than codominant trees (370 to 402 kg/m^3) in New Zealand (Anon., 1949), indicating that slower tree growth does not necessarily result in higher wood density. In a trial of fast-grown and slow-grown trees of *P. patula* in South Africa, the radial increase in wood density was similar regardless of the rate of growth (Banks and Schwegmann, 1957; Schwegmann, 1956). A study to determine wood density patterns in trees for the Meru Forest Project, Tanzania, was conducted by Lema *et al.* (1978). They found no relationship between rate of growth and wood density.

A comparison of slow-grown and fast-grown trees of *P. patula* from Viphya Plateau, Malawi, revealed no differences in wood density (Palmer and Gibbs, 1974). However, individual trees were more variable in the slow grown group. Ringo and Klem (1980) found that 25 year old *P. patula* from Sao Hill, Tanzania, showed differences in wood density between trees of up to 40% though the average value was 410 kg/m^3. There was no significant difference between large trees and small trees in wood density.

Sites of lower rainfall in South Africa (Turnbull, 1947a,b) produce wood of lower density in *P. patula*. However, many of these higher altitude sites are also associated with colder temperatures, especially in the winter months. de Villiers (1965) found the wood density of *P. patula* grown at higher altitudes in South Africa to have lower wood density and lower percentage latewood. This could be due to lower winter temperatures and/or lower winter rainfall.

An extensive study of extracted wood density variation in *P. patula* on 147 sites in South Africa was reported by Schutz (1989). For trees of an average age of 38 years, the inner density (rings 1 to 8) and the outer density (rings 23 to 30) were determined. Both inner and outer density differed significantly across sites. The correlation of rainfall with inner density ($r = 0.37$) and altitude with outer density ($r = -0.31$) were among the highest reported in this study. The effect of altitude on outer density was mostly related to temperature.

A detailed study of wood density in *P. patula* from Natal, South Africa, found that height was the most important parameter influencing wood density (Boden, 1982). Altitude was inversely correlated with wood density in that study. In Colombia, Ladrach and Lambeth (1991) also found wood density to decrease as the altitude of planting increased in *P. patula*. Kromhout and Toon (1978) note a similar trend for South African conditions. *P. patula* at six sites ranging in altitude from 1670 m to 2130 m and in age from 11 to 22 years in Tanzania was evaluated by Lubomir (1969); the mean wood density was 436 kg/m^3 and individual sites varied from 354 to 447 kg/m^3.

The South African average for wood density of *P. patula* was reported by Scott (1949) to be 482 kg/m^3 (range 337 to 674) at a moisture content of 10%. The green/freshly sawn wood density was 1043 kg/m^3. All samples were taken from wedges removed from a cross-sectional piece cut at a height between 4 m and 7.2 m. The average value presented by Scott (1935) was 417 kg/m^3 (range 337 to 642), also at a moisture content of 10 %. One speculates whether the higher density average reported in 1949 versus 1935 was the result of sampling older trees. The South African Bureau of Standards (SABS) prescribed a minimum density of 400 kg/m^3 at 12% moisture content for structural timber (de Villiers, 1974) and a maximum of 560 kg/m^3.

Barnes *et al.* (1992) evaluated wood density in eight year old *P. patula* in Zimbabwe. A wood density (kg/m^3) of 306 with a coefficient of variation of 12.3% was recorded for trees from Martin forest. Corresponding values of 335 and 8.4% were recorded for Stapleford. It is interesting to note that the site with higher wood density was less variable on an individual tree basis.

One cause of concern with *P. patula* is the presence of nodal swellings, which can reduce lumber strength by 30% in the most severe cases (Anon., 1969). In South Africa, Banks (1956) found that trees with nodal swellings had significantly higher wood density than those without nodal swellings. In a field evaluation of 5,311 trees, only 7% were free of nodal swellings (Schutz, 1989). Bumps started developing immediately after pruning though not all pruned trees had nodal swellings. There were more trees with this characteristic at lower altitude sites.

According to Gerischer and de Villiers (1963), pruning of *P. patula* resulted in wood that was significantly more dense than unpruned trees. The percentage latewood was higher in trees that were pruned. Pruning can improve the form of the tree and this reduced taper will result in greater lumber recovery (Adlard, 1964).

The technique of X-ray densitometry was used to study pruning effects on *P. patula* from Malawi (Plumptre and Austin, 1978). Trees were pruned to 60% of total height at age seven years and assessed for changes in wood density at age twenty years. Total height increased from 12.4 m to 25.6 m during the course of the study. The pruning reduced volume growth for three to four years following treatment and increased slightly the average wood density of the tree.

Plumptre (1979) has cautioned that severe pruning can result in pronounced changes in wood density of *P. patula*. He suggested that severe pruning in young trees be used to increase the wood density in the juvenile core. However, it must be remembered that a pruning of 50% of the total height can depress diameter increment in *P. patula* (Karani, 1978; Endo and Velez, 1992a,b).

It must be stated that wood density will vary due to rainfall, temperature, soil parameters and the management practices of spacing, pruning, fertilization, thinning and rate of growth. At present there are few equations capable of predicting wood density on sites that were not used originally to develop the equation, and thus extrapolation to new sites is difficult. The ability of pruning to increase wood density and result in a less variable transition from juvenile to mature wood warrants further research. The use of densitometric evaluation would allow the variation of wood density from pith to bark to be more accurately quantified. Density is often said to be the most important characteristic of wood for most utilization aspects; however, as Goodwin-Bailey (1989) has cautioned: "Wood density, as a single factor, is not a sufficiently reliable predictor of paper properties to substitute for direct measurements made from pulped samples".

3.3 Age Effects

The radial variation of wood density is of concern due to the large differences encountered from pith to bark (Table 3). For example, in thirty year old trees in South Africa, van Vuren *et al.* (1978) found that at a height of 7 m, the outer wood can be 192 kg/m^3 heavier than wood near the pith of the tree, and, thinning in a seed production area resulted in reduced wood density in the rings formed after the thinning (Anon., 1964). Wood density was lower in the upper portion of the stem (South Africa - Stohr,1980; New Zealand - Orman, 1952) though higher in the outer portion of the stem (Kenya - Chikamai, 1986,1987a,b).

On the Viphya Plateau, Malawi, the juvenile core of *P. patula* persists until 6 to 8 years of age (Adlard *et al.*, 1979). The juvenile core in *P. patula* in South Africa is reported by de Villiers (1966) to consist of the first twelve rings from the pith. Trees of *P. patula* at age 27 years in Tanzania were found to still be increasing in wood density and fibre length (Ringo, 1985a,b). The juvenile period was present until the eighth growth ring and was 49% of total stem volume. The proportion of juvenile wood was 60% for 18 year old trees in Kenya (Chikamai, 1987a,b).

In a study of 44 trees of *P. patula* that were 20 years of age or older grown in the Eastern Transvaal, South Africa, de Villiers (1965, 1972) found that wood near the pith had higher density than wood at rings 4 to 6, where wood density was the lowest. A similar observation was made by Adlard *et al.* (1979) for trees from Viphya Plateau, Malawi.

Plumptre (1972, 1978), in an extensive study of *P. patula* from Uganda, observed a strong correlation between wood density at age five years with subsequent whole tree density at age 20 years. There was a sharp transition from core to mature wood where a severe pruning had occurred. The juvenile-mature correlation for 153 trees of *P. patula* at 15 to 20 years of age in Madagascar was $r = 0.34$ ($p < 0.05$), though this correlation varied across the three sites tested (Bedel and Rakotovao, 1973; Durand, 1983). In Uganda, the correlation of wood density at an age of 4 to 5 years with that of 15 to 17 years was good ($r^2 = 70\%$ to 80%, Plumptre, 1976).

The variation of wood density due to age is one of the most important aspects affecting the use of *P. patula* wood. This is due to the change in wood density in the radial direction and with height up the stem. As in other pine species, wood density of *P. patula* was higher on older trees and on lower portions of the stem.

4. Tracheid and Other Fibre Dimensions

The tracheid dimensions are important especially for pulp and paper-making. There is not total agreement as to which are the most important tracheid dimensions or even to any minimum accepted value(s), although it is argued that the outer secondary wall of the tracheid is very important in determining the response to refining. Emerton and Goldsmith (1956) found that even light refining can remove rather large areas of the outer layer of the secondary wall in *P. patula* tracheids. Electron microscopy of *P. patula* has confirmed the presence of warty structures on the S_3 or tertiary layer (Liese and Cote, 1960). The authors stated that the warty structure could have some influence on the diffusion of pulping liquor or preservative solutions. A possible explanation of the function of the warty structures was that they may influence the diffusion of liquids through the cell walls (Liese, 1960).

Brister (1960a,b) observed that tracheid length stabilized at an age of 9 to 10 years which was at a distance of 6 to 12 cm from the pith. The author concluded that age was more important than size in determining tracheid length. Burley *et al.* (1970a) suggest that a minimum of 50 tracheids need to be measured to accurately determine the length in *P. patula*. Further details of tracheid dimensions reported for *P. patula* are summarized in Table 4.

Table 4. Tracheid characteristics of *P. patula* from various locations. The characteristics include length (L), cell wall thickness (CW), lumen width (LW), radial lumen width (RW), tangential lumen width (TW) and tracheid width (T). All data are in microns, except length in mm.

Reference	Location	Age (yrs)	Characteristics	Comments
ring basis				
Burley *et al.*, 1967a	-	-	L 2.02 L 6.15	ring 2 ring 22
Burley *et al.*, 1970b	Zimbabwe	45	T 13.10 T 2.16	ring 2 ring 30
Kromhout, 1973	South Africa	-	L 1.8 L 5.0	ring 2 ring 28
Lubomir, 1969	Tanzania	22 22	L 2.78 L 4.34	rings 1-6 rings 7-22
Malan and Hoon, 1991	South Africa	16	L 2.33 L 3.83	ring 2 ring 14
Ringo, 1983	Tanzania	27	L 2.22 L 3.99	ring 2 ring 22
Ringo and Klem, 1989	Tanzania	27	L 2.22 L 3.86	ring 2 ring 20
Uprichard, 1970	New Zealand	28	L 2.6 L 4.4	rings 1-5 rings 16-20
Uprichard and Gray, 1973	New Zealand	25	L 2.6 L 4.9	rings 1-5 rings 21-25
Zobel, 1965	Mexico	-	L 3.1 L 4.77	rings 1-10 rings 31-40
other				
Cevallos and Carmona, 1981	Mexico	-	L 2.03	
Dyson, 1971	Kenya	7	L 2.84	
Escobar and Uribe, 1970	Colombia	7 9.5	T 28.91 to 55.39 T 37.38 to 72.98	
Gonin, 1973	South Africa	40	CW 8.9, T 40.9 CW 6.0, T 37.7	first log last log
Guth, 1970	Argentina	7	L 2.1, T 50	
Kromhout, 1973	South Africa	15 5	L 3.50 L 2.82	
Ladrach, 1975	Colombia	17 9	L 4.14 L 3.20	
Lubomir, 1969	Tanzania	11 22	L 3.02 L 3.84	
Palmer and Gibbs, 1974	Malawi	16 13	L 3.2, T 53.4, CW 5.0, LW 43.4 L 2.7, T 53.6, CW 5.0, LW 43.6	
Palmer *et al.*, 1984	Tanzania	14 6	T 38.30, CW 6.21, L 3.03 T 38.30, CW 4.11, L 2.47	
Patterson, 1968a, b	-	5 20	L 2.82 L 3.91	
Paz and Olvera, 1981	Mexico	-	L 2.03 TW 29, CW 4 TW 16, CW 6	earlywood latewood
Petroff, 1968	Angola	-	L 3.5 to 4.5	
Petroff *et al.*, 1968	Madagascar	-	L 3.62 to 5.02 CW 11.4 to 13.1 LW 33.9 to 49.7	
White *et al.*, 1980	Tanzania	19 22	L 3.8 L 3.4	2380 m alt. 1660 m alt.
Zobel, 1965	Mexico	-	L 3.74 L 4.41	Tlaxcala Pueblo

Mean (range) tracheid length increased from 2.07 mm (1.92 to 2.21 mm) at age seven years to 3.75 mm (3.51 to 4.00 mm) at age 15 years in *P. patula* from Kenya (Anon., 1962). Tracheid diameter (range) in microns also increased from 49.0 (44.9 to 53.1) to 54.4 (51.1 to 57.7) as age increased from 7 to 15 years. Part of the increase in tracheid diameter was the result of the increase in tracheid wall thickness from 5.8 microns (5.3 to 6.3) to 7.6 (6.8 to 8.4) in older trees. The change in tracheid dimensions accounts for the different hand sheet properties between trees from thinnings (7 years) and final crop trees (15 years).

In a seed production area in South Africa, *P. patula* tracheid length decreased in the rings that were formed immediately after a thinning (Anon., 1964). Tracheid length was measured at 3.3 m intervals up the stem of the tree of *P. patula* (Anon., 1967); the lengths were similar in rings of equal numerical order from the pith regardless of the height in the tree. Tracheid length was found not to vary significantly with cardinal directions in 27 year old trees of *P. patula* grown in Sao Hill, Tanzania (Ringo and Klem, 1986).

Ladrach (1975) reported the tracheid length as 3.07 mm in juvenile wood and 3.85 mm in mature wood of *P. patula* in Colombia. This difference was statistically significant ($p < 0.001$). Ladrach (1984) also reported that tracheid length decreased with an increase in altitude (1800 m to 3000 m) in Colombia.

For *P. patula* in Mexico, the mean tracheid diameter was 30 microns with a range of 20 to 44 (Eguiluz, 1978). The author found that uniseriate rays were more numerous than fusiform rays and the average length was 114 microns with a range of 75 to 240. Resin canals were present at 0.3 per mm^2 in the cross-section with a mean length of 114 microns and a range of 129 to 160.

Latewood bands are thinner on *P. patula* grown in cooler temperate regions of South Africa (Kromhout and Toon, 1978). However, no difference in tracheid length was apparent between cooler temperate and warmer sites. Burley *et al.* (1972) concluded that the concept of latewood had little meaning for the species growing in Central Africa. Further data for latewood percentage can be found in Table 5.

Twelve year old trees of *P. patula* from Kenya were evaluated for tracheid characteristics (Chikamai, 1986; 1987a,b). As the distance from the pith increased to 13 cm, there was an increase in tracheid length, cell wall thickness and tracheid diameter. For the same samples, lumen diameters remained fairly constant in size. As the sample height increased from 1.3 m to 20.0 m, a decrease in size of tracheid length, cell wall thickness and tracheid diameter was noted.

Five trees of age 10.5 years from Helvetia, Eastern Transvaal, South Africa, were compared for tracheid dimensions (Wright and Malan, 1991). Latewood percentage varied from 4.6% to 10.8% between trees with respective wood density values of 421 kg/m^3 and 470 kg/m^3. Cell wall thickness varied from 5.60 to 7.38 microns between trees. Lumen area was 359 to 718 square microns, indicating a large difference between trees.

In five trees of 16 year old *P. patula* from the Eastern Transvaal, South Africa (Malan and Hoon, 1991), the mean tracheid length increased from the base of the tree (2.76 mm) to samples taken at 75% of total height (2.93 mm). Tracheid length was significantly different for tree ($p < 0.05$) and rings ($p < 0.01$) but not for height. In this study the average latewood percentage between trees varied from 13.8 to 23.8. The latewood percentage decreased from

31.4% at the base to 11.3% at 75% of total height. At ring two, the latewood percentage was 7.5%, increasing to 52.7% at ring 14. Latewood percentage was significantly different for trees ($p < 0.001$), height ($p < 0.05$) and rings ($p < 0.001$). There were no significant differences due to tree, ring or height for lumen diameter or cell wall thickness in earlywood or latewood.

Table 5. Latewood percentage of *P. patula* from various locations.

Reference	Location	Age (yrs)	Latewood	Comments
ring basis				
Burley *et al.*, 1970b	Zimbabwe	45	4.5 25.8	ring 2 ring 30
Burley, 1973	Malawi	-	7.99 15.13	ring 4 ring 8
Howland and Paterson, 1971	Malawi	25	13 48	rings 1-3 rings 16-25
other				
Gonin, 1973	South Africa	40	10.8 21.4	first log last log
Howland and Paterson, 1971	Malawi	25	38 29 23	30 cm height 7 m height 21 m height
Lubomir, 1969	Tanzania	11 22	24.8 38.5	
Orman, 1952	New Zealand	37 45	15.3 20.5	
Patterson, 1968a, b	Kenya	5 20	19.9 30.3	
Ringo, 1983	Tanzania	27	22.25	
Skolmen, 1963	Hawaii	12 30	17.6 30.9	

For 13 trees of *P. patula* at age 17 years in Howick, Natal, South Africa, Wright and Sluis-Cremer (1992) reported tracheid dimensions measured using a scanning electron microscope. For measurements made on the fourth, eighth and twelfth rings, there were increases in tracheid length as well as lumen width of both earlywood and latewood. Latewood percentage of individual trees varied from 18% to 57%, with a mean value of 31%.

The tracheid and other fibre dimensions will effect paper-making traits. The transition from juvenile to mature wood at ages 6 to 10 years will determine the relative proportion of different tracheid types (earlywood or latewood) in a tree. As in other pines, tracheid length and latewood percentage increased with tree age of *P. patula*. There needs to be more effort to correlate tracheid dimensions with paper-making traits to allow selection and breeding for these important economic uses of *P. patula*.

5. Wood and Tree Defects

Defects can reduce the value of lumber, poles, post, pulp and paper. However, there is often insufficient attention to these defects in forest management.

5.1 Spiral Grain

Spiral grain affects the strength and warping of wood. This spirality will result in twist in lumber and poles though it should be stated that spiral grain logs can be sawn without difficulty when green. Twist due to spiral grain increases as moisture content decreases (see also 12.4).

Methods of measuring spirality in sawn wood samples are described by Kromhout (1966). When taking increment cores of *P. patula* to measure growth stress, Wilkins and Bamber (1986) have cautioned that a reduction in tangential and longitudinal core diameter occur. This diameter reduction is itself related to growth stress and one should leave the cores for 48 hours prior to measuring.

Gerischer and Kromhout (1964) stated that selection against spirality must be incorporated into tree breeding programmes in order to reduce warp and twist, and thus increase lumber strength. Banks (1969) stated that tree breeding offers the best long term solution to reduce spiral grain in *P. patula.* This was confirmed by Schutz (1989), who found that site accounted for very little of the variation (0.06% to 4.43%) present in spiral grain. Variation between trees accounted for the remainder, and it is this variation that can be exploited through selection and breeding. However, Paterson (1968a,b) found the parent-offspring correlation for trees selected for low spiral grain to be low ($r = 0.17$) for progeny at age 3 to 4 years, indicating that selection had not been effective or that juvenile-mature correlations were low.

Gerischer and Kromhout (1964) state that spirality is higher in the juvenile core than in mature wood. For example, spirality in the first five growth rings of *P. patula* could approach 3.5^0 while the value in rings 10 to 35 could be 1.5^0. These values were derived from measurements of over 2,400 trees sampled for tree breeding purposes.

de Villiers (1972) also reported the spiral grain to decrease as one moved from the pith to the exterior of the tree in South African grown *P. patula*, varying from 3.45^0 at ring two from the pith to 2.61^0 at ring 36 (de Villiers, 1974). Kromhout and Toon (1977) reported that spiral grain measured at ring number 32 was greater in warmer areas (2.1^0) than in cooler temperate areas (1.3^0).

In a sample of six 30 year old trees grown in Central Africa, it was found that grain angle differed significantly due to tree (range of 0.61^0 to 3.32^0), height of the sample and radius (Burley *et al.*, 1967b). The variable results for grain angle measurements within a tree indicated the need at the time for further refinement of the measurement techniques.

For a sample of 235 12 to 40 year old trees of *P. patula* grown in East Africa (Kenya, Uganda and Tanzania), only 2.4% would have been classified as unsuitable for structural timber based on grain angles measured on increment cores (Paterson, 1968a); the criterion for plus tree selection in the East African Tree Breeding Programme was grain angle of not more than 6^0. In a study of 192 *P. patula* trees of 15 years of age at Kinale, Kenya, grain angle was not related to tree size or to the angle of lean of a tree (Paterson, 1968a).

From a select population of *P. patula* from East Africa, grain angle decreased from 3.7° to 3.3° as tree age increased from 5 to 20 years (Paterson, 1968b). Contrary to other reports, Paterson (1968d) stated that spiral grain "is not a serious defect and breeding work is unlikely to improve it much".

In *P. patula*, spiral grain is highest in the juvenile core, which can nevertheless affect boards sawn some distance from the pith (Banks, 1969). The author suggests that logs with a top diameter of 25.4 cm should be sawn into boards of 2.54 cm thickness or less since these boards can be more readily restrained than thicker boards. Logs with a top diameter of 27.94 cm or larger should be sawn into boards of 3.81 cm or 5.08 cm thickness and a width of 15.24 cm. Boards from larger logs will have proportionally less juvenile wood and are therefore more stable in seasoning.

Spiral grain reduces the strength of timber by 10 to 25 per cent when grain angle is 5° and 8° respectively. This defect can result in degrade due to warping of sawn lumber (Burley *et al.* 1967b). At one time, spiral grain was given the highest weight of any wood characteristic in the selection index for *P. patula* in South Africa (de Villiers, 1974). For a general and recent account of spiral grain, the reader is advised to consult Harris (1989).

Spiral grain will result in increased degrade in lumber. However, if the majority of the wood produced in a planation will be used for pulp there is no published evidence which states that spiral grain will have an adverse effect on any pulp or paper-making trait.

5.2 Compression Wood

The most important defect due to compression wood is the high longitudinal shrinkage in boards, resulting in both excessive warp and lower strength of boards with a high proportion of compression wood. Compression wood will also increase the consumption of cooking liquors in pulping and a reduction in pulp yields.

Howland and Paterson (1971) studied *P. patula* at age 25 years in Dedza Mountain, Malawi. The proportion of compression wood in the first 7 m log was 25%, with a coefficient of variation of 48%. In 29 year old *P. patula* from Tanzania (Meru Project) the wood density of compression wood was 12% higher than that for normal wood (474 kg/m^3 to 425 kg/m^3; Ishengoma *et al.*, 1990). Tracheid lengths of 20 trees in that study were 35% shorter in compression wood than normal wood (3.4 mm cf. 4.6 mm).

Geary (1970) stated that compression wood leads to lower pulp yields and that, in order to decrease the amount of compression wood, only straight trees should be included in a tree breeding programme. Lumber containing compression wood can be detected due to excessive spring and bow during seasoning (de Villiers *et al.*, 1961).

Similarly van der Sijde and Denison (1967) suggested selection for stem straightness to minimize compression wood; they also stated that compression wood near branches can be reduced by selection and breeding for trees with smaller branches. In East African grown *P. patula*, Paterson (1968b) selected trees for a breeding programme with 12% compression wood, compared to a population mean of 19%.

It would seem that the incidence of compression wood in *P. patula* is of concern. However, selection and breeding for improved straightness may reduce the number of trees with this deleterious characteristic.

5.3 Nodal Swelling

Nodal swellings (stem corrugations) on the stems of *P. patula* is a concern in South Africa. Banks (1956) observed that lumber from trees without nodal swellings had significantly higher modulus of rupture than trees with nodal swellings. However, lumber hardness was significantly greater when the boards came from trees with nodal swellings.

Nodal swellings of *P. patula* give considerable handling problems in saw mills. An extensive study in South Africa, of over 5,000 trees in 150 stands, was conducted to elucidate possible causes (Anon., 1984). Serious nodal swelling was found on 10% of the trees, but only 7% of all trees were free of this trait, which developed after pruning. However, nodal swellings not associated with pruning were caused by hail damage. Wind damage can also result in nodal swelling in *P. patula* in South Africa (Anon., 1971).

Schutz (1989) sampled 20 trees representing different levels of nodal swellings from two stands at Mac State Forest (South Africa). Logs from the lowest 3 m section of the stem were sawn into boards, kiln-seasoned and planed. Boards sawn from trees with nodal swellings had severe grain deflection and grain separation.

5.4 Branching and Pruning

de Villiers (1965) noted that *P. patula* in South Africa tended to develop fairly heavy branches, and that the yield in structural timber was very low when older, heavily branched trees were being sawn. Pruning could begin as early as four years of age in *P. patula* plantations in South Africa (Sherry, 1961). Skolmen (1963) reported steep branch angle and the lack of self pruning as being deleterious traits of *P. patula* in Hawaii. Sherry (1967) reported that pruning to a height of 8 m was financially justified though pruning to a height of 13 m was not, and that pruning to reduce the knotty core to 12.7 cm diameter led to a reduction in volume growth. Lewis (1964) reviewed pruning and thinning regimes then in use in South Africa. Centre boards of *P. patula* were of very low quality, due to large knots. However, flitches of 7.6 cm width did commonly have one defect free face.

An extensive study of the quality of *P. patula* lumber in South Africa found that rejects totalled 17%, due almost solely to the size of edge knots (Scott and Stephens, 1947). The authors reported the yield from round logs to squared and seasoned lumber as 53%. Luckhoff (1956) reported concern about the high incidence of loose and decayed knots in South African grown *P. patula*, and stated that a tree must have at least 10.5 cm of diameter growth after pruning to justify the cost of this silvicultural treatment for improved lumber quality.

Extensive studies have been made of the economic benefits of pruning in *P. patula* by, amongst others, Bosman (1967) and Luckhoff (1949; 1956).

The economics of pruning will depend on end uses and the willingness of management to pay the costs. There is also the belief that pruning will reduce the incidence of fire hazard; however the author could not find any references to substantiate this for *P. patula*.

6. Bark

The amount or depth of bark on a tree will vary with age, site, altitude, position of sampling and method of measurement (volume or weight). Weight will also vary according to whether it is expressed as a green, air-dried or oven-dried basis. The bark content reported for *P. patula* across a range of sites is given in Table 6.

Table 6. Bark content (%) of *P. patula* from various locations, determined on a volume (vol.) or weight (wt.) basis.

Reference	Location	Age (yrs)	Bark	Comments
Brasil *et al.*, 1982	Brazil	20 20	12.59 11.85	vol., whole tree vol., to 3 cm limit
Howland and Paterson, 1971	Malawi	25	9.6 (c.v. 23.2)	wt., 1600 m altitude
Ladrach, 1986a	Colombia	8	22	vol.
Ladrach and Lambeth, 1991	Colombia	7 7	32.6 16.5	vol., 3050 m altitude vol., 2500 m altitude
Morris, 1985a	Swaziland	28 18	2.7 5.1	wt., to 25% of height wt., to 25% of height
Palmer and Gibbs, 1974	Malawi	16 16	9 19.5	vol., fast grown vol., slow grown
Palmer *et al.*, 1982	Kenya	20 20 10 10	3-9 4-10 5-10 7-18	wt. vol. wt. vol.
Palmer *et al.*, 1984	Tanzania	14 6 14 6	5 15 5 13	vol. vol. wt. wt.
Stohr, 1980	South Africa	14 14	13.6 11.8	vol. wt.

The bark component of *P. patula* is important since it can be readily composted and used as a medium in seedling nurseries. Stohr (1980) found that, for South African-grown trees at age 14 years, the moisture content of the bark increased from 56.6% at 0.3 m height to 247.3% at a height of 14.7 m; corresponding densities were 458 kg/m^3 and 820 kg/m^3. A similar trend with height was observed for 21 year old trees. Davis *et al.* (1991) evaluated the conditions necessary for composting a mixture of bark of three pine species, including *P. patula*, in Natal, South Africa. They found the numbers of bacterial colony forming units (CFU) to be higher than fungal CFU and that addition of urea increased the bacterial numbers more than did the addition of nitrate. If an acceptable source of nitrogen were not added, the high temperatures associated with composting would not occur.

In Colombia, Ladrach and Lambeth (1991) evaluated the bark volume in seven year old *P. patula* at two sites, Carpenterias (2500 m) and Neusa (3050 m). Heritabilities on an individual and family basis were, respectively, 0.47 and 0.78 at Carpenterias and 0.29 and 0.67 at Neusa.

In general, bark content will be higher in younger trees and in trees grown at higher altitude. Bark would not normally be desirable on wood processed for pulp, lumber, poles and posts. However, the use of bark as a compost material for seedling nurseries is promising. For mills processing pulp, lumber or other products, any effort to derive new and economic uses for the vast quantities of bark generated would be most beneficial. Alternatively, removing the bark in the field would allow the return of accumulated nutrients to the soil. This practice would be less feasible for large industries where the bark is burned for fuel, as is often the case in pulp, paper and saw mills.

7. Biomass

The biomass of a tree is comprised of bark, roots, needles, wood and branches, and can be expressed on the basis of weight, volume or height. Wood yields of *P. patula* from commercial plantations have been predicted for South Africa (Craib, 1939; Crowe, 1967; Bredenkamp, 1980; Cawse, 1983), Malawi (Marshall and Foot, 1969), Brazil (Kronka, 1974), India (Ghosh and Guhathakurta, 1973), Swaziland (Evans, 1974), Tanzania (Malimbwi and Philip, 1989) and Kenya (Wanene, 1975).

Caballero and Prado (1969) gave the height of *P. patula* in plantations at an altitude of 1650 m in Michoacan, Mexico, as 2.0 m at age two years and 6.65 m at age five years, indicating the rapid growth attainable in Mexico. In Hawaii, Whitesell and Le Barron (1976) reported that height growth of one metre per annum was common for the species.

Vega (1965) reported the annual growth rate of *P. patula* in Cundinamarca, Colombia, as 20.6 and 11.5 cubic metres per hectare at ages 22 and 15 years, respectively. Adegbehin (1982) gave a mean annual increment of 40.6 m^3/ha at age 20 years on the best site at Sao Hill, Tanzania. Over a 30 year rotation in South Africa, the total commercial volume production was 516 cubic metres per hectare (Kromhout and Bosman, 1981).

Schonau *et al.* (1981) found a wide variation in the volume/mass ratio for recently felled *P. patula* from Natal, South Africa. Between 1.27 and 1.46 cubic metres were required to produce a ton of dry wood; the normal value for industrial conversion in South Africa with the species is one cubic metre per ton of dry wood.

Pulpwood stands on the Viphya Plateau, Malawi, with a rotation of 15 years would yield 75 to 125 tons/hectare of oven-dry wood (Palmer and Gibbs, 1974); thinned stands would yield 62 to 100 tons/hectare of oven-dry wood at 15 years from planting. For *P. patula* stands at age 14 years near Agudos, Sao Paulo, Brazil, the oven dry weight of wood produced per hectare per annum was 6.352 tons (Ferreira *et al.*, 1978). For *P. patula* in the region of Moji Guacu, Sao Paulo, Brazil, the dry weight on an individual tree basis at twenty years was 130.11 kg with bark and 114.09 kg without bark (Brasil et al, 1982). Ladrach and Mazuera (1978) evaluated the wood production of *P. patula* at San Jose, Colombia, at an age of 6.3 years. The total dry and total green weights of wood per hectare were 46 tons and 127 tons, respectively. In a further study, Ladrach (1978) reported an equation for total dry weight inside bark as: Weight in kgs = $-3.1754142 + 0.0118079D^2H$, where D is diameter at breast height (cm) and H is total height (m).

The development of predictive equations for total dry wood production of *P. patula* at age 21 years in Brasil has been given by Pinheiro *et al.* (1986). The equation for a given diameter (D) and height (h) was: $\log_e Pt = -7.3929 + 1.53242(\log_e D) + 2.66434(\log_e h)$. In Colombia, Cordoba (1985) gave a yield equation for *P. patula* as $\log_n$ Green Weight outside bark = $8.795693 + 0.032831$ (SI) $+ 0.985621$ ($\log_n$ BA) $- 6.011530$ (1/T), where SI is the site index at 15 years in metres, BA is the basal area (m^2/ha) and T is the age in years.

When rainfall was 76% and 83% of normal levels in two consecutive years, there was a 5% decrease in total forest productivity for *P. patula* in Swaziland (Evans, 1978). A severe locust infestation on *P. patula* at Woodbush, Northern Transvaal, South Africa, in 1934 resulted in a marked loss of increment in 1935 and 1936 (Turnbull, 1937).

One important consideration in biomass production is the contribution of water to yields that are not calculated on an air dry or oven dry basis. Ladrach (1986b) observed that wood from younger trees contained more water than that from older trees; trees at seven years of age produced 369 kg of wood per green ton, compared to 651 kg of wood per green ton for trees at 30 years of age.

Morris (1982a) studied aboveground biomass production on *P. patula* from the Usutu Forest, Swaziland. With a total volume of 0.898 m^3 and a dry weight of 500.9 kg, a 30 year old tree comprised 397 kg of stemwood, 39.1 kg of bark, 58.4 kg of branches and 6.4 kg of needles. An 18 year old tree with a total volume of 0.299 m^3 and weight of 160.2 kg comprised 121 kg of stemwood, 13.4 kg of bark, 19.7 kg of branches and 6.1 kg of needles. For a three year old tree with a diameter at breast height of 5.7 cm and a height of 4.4 m, the total biomass of 18.1 kg comprised 8.92 kg of stemwood, 3.63 kg of branches and 5.66 kg of needles. On a per hectare basis in the same forest, Morris (1985b) reported that the total production of 247.6 tons (oven dry basis) comprised stemwood (175.1), stem bark (14.7), live branches (15.0), needles (3.8), dead branches (10.5) and roots (28.5). Morris (1993) cautioned that low rates of decomposition for *P. patula* at higher elevations in Swaziland may result in increased levels of nutrient immobilization.

The biomass production (oven dry basis) of *P. patula* grown in the Darjeeling Hills, India, was monitored by Singh (1982) and Bajrang (1982). Comparisons between stands that were 8 or 25 years of age were made in tons per hectare for the bole (1.21 versus 324.69) branches (3.03 versus 39.00) and needles (2.56 versus 10.89). The annual litter fall was 11.42 tons per hectare. Further evaluations of biomass productivity (oven-dry basis) were undertaken in *P. patula* plantations in Palni Hills, Tamil Nadu, India by Sharma and Srivastava (1984). The authors found that suppressed trees at age nine years had wood production of 35.13 kg/tree while dominant trees produced 141.78 kg/tree. The nine year old plantation had a total above ground biomass of 171,579 kg. A total of 57% of the biomass at age nine years was wood.

In Nilgiris, Tamil Nadu, India, (latitude 10^0 to 11.75^0N, altitude 2200 m, rainfall 1500 to 2500 mm/annum, heavy frost) *P. patula* plantations of 6, 8, 10, 12 and 14 years of age were sampled for dry weight (Malhotra *et al.*, 1985). The total biomass per hectare increased from 18,482 kg at age six years to 210,238 kg at age fourteen years. The wood portion of the biomass increased from 35.8% at age six years to 55.7% at age ten years. The root portion of the biomass decreased from 35.5% at age six years to 23.8% at age fourteen years. As expected, the bark portion of the biomass decreased from 8.0% to 5.3% at ages six and fourteen years, respectively. It is interesting that the productivity (kg/tree/annum) was 2, 16 and 11 at the ages of 6, 10 and 14. Where the objective is to restore biological productivity to degraded sites, a partial or total harvest at age ten years for this site would be advisable.

Sampling was undertaken in *P. patula* stands at various ages in Darjeeling and Kalimpong Forest Divisions, India, at a latitude of 26° to 27°N, altitude of 1900 m, mean annual rainfall of 2500 mm and mean annual temperature of 11.0°C with moderate to severe frosts (Bhartari, 1986). From age 4 years to age 14 years, the above ground biomass (oven-dry basis) increased from 13.06 kg/tree to 287.98 kg/tree. The mean weight of wood (bark) in kg/tree was 5.08 (0.75) at age 4 years and 164.54 (23.50) at age 14 years. The author noted that the maximum rate of increase in dry mass of non-photosynthetic components was at 12 years.

The ability of *P. patula* to produce considerable biomass on degraded sites is proven. As the age of the stand increases a larger proportion of the biomass is in the stem. Whether this is desirable in terms of long term productivity has not been thoroughly addressed but this aspect can not be overlooked in any tree planting programme.

8. Charcoal and Fuelwood

The use of *P. patula* for charcoal is common in many countries, though very few reports have been dedicated to this subject. In Uganda, charcoal made from *P. patula* was found to be suitable for iron-smelting due to the high hardness which results in fewer losses during transport (Earl, 1974).

Ishengoma and Klem (1979) stated that the yield of charcoal from wood of moisture content at 40% to 50% was 63 kg per cubic metre of wood. From the hardness index, charcoal from *P. patula* was acceptable and no large losses in transport or handling would be expected. The cost of production increased at higher wood moisture contents and as the size of the wood decreased. There were complaints that *P. patula* charcoal burned faster than hardwood charcoal. For this study in Tanzania, it was noted that traditional conversion of wood to charcoal can result in as much as 70% loss of the calorific value of the wood. This would be somewhat offset by lower transport cost of charcoal compared to wood.

In Malawi, Zieroth (1988) reported on a pilot trial of charcoal production from *P. patula* that was producing 6,000 tons per annum. The charcoal was being marketed as fuel for tobacco drying, steam boilers and for furnaces in cement factories. The author concluded that an annual production of 60,000 tons was feasible.

Calorific value for the above ground tree components of *P. patula* in Darjeeling, India, ranged from 17.46 to 21.05 kJ on a dry weight basis and 17.68 to 21.68 kJ on ash-free dry weight basis (Singh, 1984). Between 16% and 50% of the annual energy fixed is lost in needle fall. However, with a decomposition rate of 7-15% per annum, the needle fall energy loss is not complete in a year. The net production efficiency based on solar interception varies from 0.13-2.29% in 8-34 year old stands. This value is higher than that reported for other plantation species in India.

It is an understatement that insufficient research has been done on the very important aspects of charcoal and fuelwood potential of *P. patula*. In most of the countries where the species is grown there is a large dependence on fuelwood for cooking. Improved methods for charcoal manufacture, as have been developed for eucalypt wood in Brazil, could improve the standard of living in rural areas where *P. patula* is grown. The author has observed branches and small stems being used for charcoal production in Colombia. The use of residual woody material for charcoal manufacture following clear felling of a forest should also be evaluated in terms of the capacity of a site to sustain the removal of nutrients removed in this manner.

9. Wood Degradation and Preservation

9.1 Untreated Wood

Wood of *P. patula* is considered to be non-durable and not resistant to attack from fungus, insects or termites (Chundoff, 1980). Untreated posts from 13 year old trees of *P. patula* were severely attacked after being submerged for six months in the harbour of Durban, South Africa (Krogh, 1961). In Tanzania, the natural durability of *P. patula* was three to nine months depending on the site (Murira, 1984). The wood tested measured 50 mm by 50 mm and 90% of the failures were from termites.

In Zimbabwe, there is customer prejudice against *P. patula* timber affected by sapstain and mould (Masuka and Kariwo, 1992). The authors report that 100% of the logs had mould or sapstain after 20 days of field storage. However, only 27% were infected 15 days after field storage. Rapid transport and processing could help reduce the presence of these deleterious characteristics.

Blue stain is a detrimental characteristic of wood of *P. patula* in Colombia though there is no reported decrease in wood strength (Solano, 1987). The author observed that logs were attacked within five days of being felled. A local product, Manzate, at a concentration of 10% was recommended as a dip treatment of one minute duration to prevent blue stain.

de Villiers (1966) suggested application of anti-blue stain chemicals to logs within 48 hours of log preparation. For sapstain preventatives in *P. patula,* Coetzee and Quinn (1978) have found that concentrations of 0.25% and 0.20% of Busan 30 and Difolatan, respectively, were acceptable alternatives to 2.0% of sodium pentachlorophenate borax (Na PCP/borax). The oral toxicities of Busan 30 and Difolatan are much lower than that of Na PCP. Plumptre (1967) suggested dipping the wood in sodium pentachlorophenate to prevent sapstain in the climatic conditions of Uganda.

Following a fire which burned 2,000 ha of pine plantations at Entabeni, South Africa, sprinkler irrigation of sawtimber was undertaken for 12 months (von dem Bussche, 1993). The daily irrigation of 75 mm did not affect timber quality. No blue stain developed during the storage period, in contrast to that which the author stated develops quickly on burnt timber. Lambeth *et al.* (1989) found blue stain infection to be worse in the dry season in Colombia, but concluded that wood stored under irrigated conditions in Cali, Colombia, had no blue stain.

Initial degradation began in the S^3 layer of *P. patula* wood chips from a chip pile in Zululand, South Africa (Rogers and Baecker, 1987). The bacterium were attached by a glycocalyx and could be the precursors for secondary and tertiary successors. From a chip pile of *P. patula* in Zululand, South Africa, an obligately anaerobic bacterium was isolated from decayed wood chips and proposed as a new species, *Clostridium xylanolyticum* (Rogers and Baecker, 1991). These wood chips had been exposed for ten months. In a test of *P. patula* boards exposed to a marine environment (Southwestern Cape Province, South Africa) there were four fungus species identified: *Alternaria maritima, Ceriosporopsis halima, Lulworthia floridana* and *Zalerion maritimum* (Gorter, 1978).

While blue stain can be controlled by a spray following felling or by storing the logs under irrigation, untreated wood of *P. patula* does decay rapidly in most of the countries where it is grown.

9.2 Treated Wood

Work on preserving the wood of *P. patula* in South Africa commenced in 1922 (Scott, 1946). An early report (Anon., 1948) stated that creosote treated wood shingles of the species had lasted ten years in use in Pretoria with such satisfactory results that further trials were planned.

The end use needs to be considered for treated wood. For example, wooden transplant boxes (for seedlings) caused mortality and yellowing of the plants when the lumber had been treated with polychlorophenol (Griffith, 1957).

FAO (1986) reported that wood of *P. patula* could be penetrated completely under pressure. Heavy impregnation using the hot and cold open tank process was also said to be feasible. Pizzi (1990) has indicated that treatment with emulsified varnish/CrO_3 gives good water repellent treatment for *P. patula* from South Africa. One method for protecting wood is through painting. In a trial with *P. patula* wood panels, it was found that the same paints behaved differently depending on the type of timber used and the climate where the boards were used (Frank and Low, 1966). It was found that painting of Tanalith 'C' treated wood gave the best results. Timber treated with creosote could not be painted.

In Madagascar, attempts have been made to treat the wood of *P. patula* (Fougerousse *et al.*, 1971). It was found that the retention of Cryptogil "C" was 5.9 kg/m^3 after 30 hours of treatment. The retention of Celcure "A" was found to be 6.6 kg/m^3 after 35 hours of treatment. The authors concluded that these water-borne preservatives were very satisfactory for sap-displacement impregnation. Bedel *et al.* (1975) described the treatment of *P. patula* posts in Madagascar. The pressurized impregnation of one end or both ends of the post using a sleeve device and CCA at a concentration of 3-4% was said to give successful field results.

Wood treatment of *P. patula* in Angola began in 1973 (Reimao, 1974). When using Tanalith CT-106, the retention (kg/m^3) varied as the concentration increased from 1% (7.6), 2% (15.1), 3% (22.0) and 5% (40.0) (Reimao, 1975).

One of the most important ground-contact heavy-duty wood preservatives for *P. patula* in South Africa is copper-chrome-arsenic (Cameron and Pizzi, 1985). At a CCA retention of 32 kg/m^3, boards joined by different adhesives (cold-setting phenol/resorcinol/formaldehyde (PRF) and wattle tannin/resorcinol/formaldehyde (TRF)) had higher strength and lower percentage wood failure than at a CCA retention of 20 kg/m^3. One reason for the better strength at higher retention levels is that CCA treated timber is slightly more porous than untreated timber due to hydrolysis of some of the cellulose (Cameron and Pizzi, 1983). They also found that lower density wood (400 kg/m^3) does not have the bonding quality of medium (500 kg/m^3) or higher (600 kg/m^3) density wood.

An important consideration in wood treatment is whether it is better to have the CCA chemicals attached to the lignin or on the holocellulose (Pizzi and Conradie, 1986). A study with *P. patula* found that higher resistance to termites resulted from a higher concentration of CCA on lignin. In terms of fungus resistance, a higher concentration of CCA on holocellulose gave higher resistance. Conradie *et al.* (1985) found more CCA on lignin than on cellulose, with a ratio of 60:40. Their observation was that the overall CCA concentration decreased towards the centre of the pole or board being treated.

It is reported that CCA acted preferentially with tannins, rather than with lignin or cellulose, in *P. patula* (Pizzi *et al.*, 1986b). This did not decrease the long term resistance to insect attack but could reduce the resistance to fungus attack. As tannin content increases in pine wood, fungal resistance is reduced; *P. patula* at 35 years of age in South Africa is at the highest level of water soluble tannins. Wood of *P. patula* in Colombia is said to be more susceptible to termite attack, due to high cellulose content (55%) and long fibres (2.87 mm) that allow more rapid destruction of the wood (Beron and Ramirez, 1985). However, following wood treatment with pentachlorophenol, termite mortality was 100% within two days of contact with treated wood.

Polyflavanoid tannins in wood can cause severe undertreatment with CCA (Pizzi *et al.*, 1986c); a tannin content of 0.15% to 0.20% is considered low for *P. patula* in South Africa. A preleaching treatment with water or solvents can reduce the tannin content prior to treatment.

One serious limitation in the use of CCA wood preservatives is the formation of solid sludges (Pizzi *et al.*, 1984). Sludge formation can result in treatment delays, choking of pumps and pipes as well as loss to sludges of usable preservative. Using *P. patula* as test material, it was found that sludge formation commences with CCA contact with wood, due to precipitation of salts from the solution extracted from wood during vacuum treatment.

Further trials on the penetration of CCA in *P. patula* have been described by Jansen *et al.* (1985). For instance, an average retention (kg/m^3) of 10 has values of 17.6 at a depth of 0 mm and 7.0 at a depth of 47.5 mm. For use in South Africa, treated wood must have a CCA retention of 6 kg/m^3 for interior use and 8 kg/m^3 for exterior use (Knuffel, 1985).

CCA treated *P. patula* that is subsequently heat treated or kiln dried will have significantly reduced resistance to insects and fungi (Conradie and Pizzi, 1987b). Also, CCA treated *P. patula* was found to have an 8% reduction in compression strength when treated to a retention of 6 kg/m^3 (Knuffel, 1985). This lower wood strength could be the result of partial hydrolysis of timber cellulose.

When boards of *P. patula* were laminated following treatment and weathered under South African conditions, it was observed that creosote or CCA with a superficial anti-weathering treatment gave better results than CCA alone (Conradie, 1985). Wood of lower density (400 kg/m^3) did not laminate as well as wood of medium and high density.

Conradie and Pizzi (1985) reported that an organic preservative, DNBP (2 sec butyl 4,6 dinitrophenol), has given long-term effectiveness against termites and fungi in South African *P. patula*. Using the full-cell process and a DNBP retention of 8 kg/m^3, the field test results over twenty years were very good. Leaching of DNBP was comparable to that of CCA. In addition, DNBP treated wood can be glued using phenolic adhesives.

The success of wood treatment over a 25 year period with DNBP has indicated a need to develop DNBP derived chemical wood treatment that will have lower mammalian toxicity (Pizzi *et al.*, 1986b). The authors reported that in tests of *P. patula*, ester derivatives of DNBP have been shown to have lower toxicity but to still offer the advantage of long term durability. Further advantages of DNBP and derivatives are absence of sludging, low or non-existent effect on timber strength and excellent gluability of treated timber. The authors recommended this treatment for wood as used in interior, exterior and ground contact applications. Further developments with DNBP wood preservatives were reported by Conradie and Pizzi (1987a).

Bariska and Pizzi (1986) have observed that tannins are easily incorporated into the walls of woody cells. They suggested that strength relative to untreated lumber would be higher in air-dried sapwood of *P. patula* that was treated with a low viscosity tannin extract to a final retention of 35.7 kg/m^3 (5 % tannin load w/w).

Agudelo and Uribe (1988) treated posts from seven year old plantations of *P. patula* from Antioquia, Colombia, with copper, chrome and boron (CCB) as a preservative treatment. The methods of treatment were in a heated solution (96 ^{0}C) or in a solution at ambient temperature, with the CCB at three concentrations (5%, 4%, 2%). Results adequate for treated wood to be in contact with soil were obtained at a CCB concentration of 4% with soaking for one hour in the heated solution or for three hours in the solution at ambient temperature. The retention required for exterior use in Colombia is 8 kg/m^3.

The treatment of *P. patula* with Tanalith C preservative gave complete penetration in 60 minutes using the full cell process (Plumptre and Kasirye, 1968). The absorption averaged 26 kg/m^3 with a range from 16.3 to 34.7 kg/m^3.

One difficult aspect of wood treatment is the assessment of solvent penetration. Pendlebury *et al.* (1991) report that a microtomed wood section of *P. patula* could be saturated using a laboratory scale vacuum-pressure process. After being placed in liquid nitrogen, the sample was evaluated using cryogenic electron microscopy for visual determination of water penetration. The characterization of water penetration could then be used to assess the effectiveness of wood treatment.

van Gent (1958) has cautioned that the analytical and calculated absorptions of chemical in treated wood of *P. patula* can be at variance. However, for Tanalith 'C' treated wood, the analytical and calculated absorption were very similar. Analyses of PCP treated wood indicated that the absorption was 20% lower than the calculated amount. This difference can affect the ability of a manufacturer to comply with local regulations regarding minimum content of preservative chemicals in treated wood.

Autio and Miettinen (1970) reported on the potential for a product called wood-polymer composite (WPC) of African pine (*P. patula*). The monomer is added to dry wood and then polymerized to form a hard, dense product. The sapwood of *P. patula* (no site or age given) was easily filled with monomer with very uniform impregnation. The high polymer content (50% of total weight) resulted in good hardness and abrasion resistance properties.

When poles derived from 13 year old trees of *P. patula* were treated and placed in the harbour at Durban, South Africa, certain treatments gave serviceable poles 96 months after exposure (Krogh, 1961). The untreated controls were severely attacked after six months. Wood treatments with promising results were A.W.P.A. creosote, pentachlorophenol (5% and 10%), copper pentachlorophenol, Tanalith 'C' and Celcure 'A' (5%).

Test blocks of *P. patula* were protected from decay by a retention of 6.92 kg/m^3 of DNPB or

10.43 kg/m^3 of CCA in soil burial tests (Schnippenkoetter *et al.*, 1988). Decay was monitored by determining weight losses over a 15 week period. The pine blocks did not decay in soil, possibly due to anaerobiosis.

Wright and Ladrach (1993) evaluated the field performance in Colombia of *P. patula* posts and poles treated with CCA. For poles, the mean CCA retention was 17.9 kg/m^3 with a range from 11.7 to 26.1 kg/m^3. The retention in the posts was 8.9 kg/m^3. At the three sites evaluated, the treated posts and poles were mostly solid with no decay after ten years of field exposure. All of the untreated poles and posts had suffered complete failure after less than two years of field exposure.

The preservative treatment of wood for tropical and sub-tropical conditions is important. In this sense, *P. patula* is a superb species since all reports indicate the total penetration by a wide range of preserving chemicals. The human toxicity of these chemicals need to be ascertained as treated wood can be mis-used. Also, more reports of field trials to evaluate different chemicals and retention times for outdoor efficacy are required.

10. Reconstituted Wood Products

As the rotation length for plantations is reduced the size of the stems is also reduced. Stem size will have an effect on lumber quantity and quality. However, small stems can be chipped and reconstituted with an adhesive to form a product that can be very useful, especially for indoor applications such as shelving or furniture.

10.1 Wood Adhesives

The development of 'honeymoon' type fast-setting adhesives for *P. patula* in South Africa have been noted (Pizzi *et al.*, 1983). It was suggested that best results would follow planing of the the timber and that any bow in the timber will result in greater strain at the glue-line, increasing the likelihood of failure. Cold setting and fast setting wood adhesives based on soda bagasse lignin satisfy international standards for exterior use structural fingerjoints of *P. patula* (van der Klashorst *et al.*, 1985).

Pizzi *et al.* (1986a) have sought solutions to degradation of wood from acid setting phenol formaldehyde resins. They report the development of chemical systems to self neutralize the acid setting resin in exterior finger jointing applications of *P. patula.*

van Rensburg *et al.* (1987) reported that high wood density (> 675 kg/m^3) can result in increased glue line failure. The authors found that finger-jointing with phenol resorcinol formaldehyde (PRF) gave only 50% of the strength values compared to visually clear lumber. Fronius (1984) stated that *P. patula* was very acceptable for the manufacture of laminated boards of various dimensions.

10.2 Particle Board and Related Products

When chips of *P. patula* from South Africa were made into particle boards using urea-formaldehyde and tannin-formaldehyde adhesive, the modulus of rupture (kg/cm^2) was 100.1 and 54.6, respectively (Parrish, 1958). In the same study it was noted that the flexural strength of particle boards comprised of *P. patula* chips was almost doubled when the resin percentage was increased from 8% to 12%. Particle board of exterior grade could be made with an extract of bark tannin from *P. patula* of South African origin (Pizzi, 1982).

Stromberg and Miettinen (1969) reported that impregnating wood chips with polyester-styrene resulted in an increase of 40% in shear strength and 700% in hardness. The increase in hardness could be especially important where the reconstituted wood was intended for flooring use.

In a trial of 16 year old *P. patula* from Parana, Brazil, Keinert (1988a) concluded that the species was very promising for extruded particle board. The boards were formed using a phenolic adhesive, wood chips with a moisture content of 5% and a press of 35 kg/m^2 at 160^0C for eight minutes. At a nominal board density of 600 kg/m^3 the modulus of elasticity (kg/cm^2) increased from 63,422 to 80,111 at adhesive contents of 4% and 6% respectively. When the nominal board density was increased to 750 kg/m^3, the corresponding figures for modulus of elasticity were 96,735 and 105,503 at the same adhesive contents.

The properties of structural composition boards from Brazil-grown conifers were reviewed by Keinert (1988b). Of the species tested, *P. patula* was one of the best in terms of strength. With 8% adhesive, the modulus of elasticity increased from 80,111 to 105,503 as board density increased from 600 kg/m^3 to 750 kg/m^3. The boards of *P. patula* were lower in linear expansion than those of any other species tested.

The use of *P. patula* for reconstituted wood products is likely to develop further. Due to the low resin content of the wood and the growing interest in this type of wood utilization, there is the need to develop appropriate technologies. Most studies of reconstituted wood products have been based on species available in north temperate regions and it is suggested that more research be undertaken to determine the potential for *P. patula* for these uses.

11. Poles and Posts

The market for poles and posts in many developing countries is increasing, with a corresponding need to identify acceptable levels of strength and longevity in field use. It is expected that plantations of *P. patula* could supply poles and posts that are presently being removed from natural forests at levels that are not sustainable.

Scott (1946) described the species as being weak for telephone poles but suggested that larger size poles or closer espacement could compensate for the lower strength. One cause for concern is that individual poles can differ by up to 17% in strength. de Villiers (1974) stated that, for South African conditions, posts and poles of *P. patula* were to have four rings in the outer 25 mm radius to have adequate strength. Kromhout (1978) states that due to low wood core density, *P. patula* makes poor poles, presumably since there are better tree species for this purpose in South Africa.

The potential of *P. patula* for utility poles in Madagascar was evaluated by Gueneau and Fougerousse (1969). Untreated poles would have a service life of less than five years, though they reported that the species was easy to treat with preservatives. However, the static flex of 972 kg/cm^2 was somewhat below that of the other species examined. One limitation on the use of *P. patula* for poles in Kenya was reduced strength due to knots (Campbell, 1971); the author stated that genetic or silvicultural improvement was required before the species could be used for telephone poles.

The use of *P. patula* posts for telephone and electrical lines in Colombia would reduce the demand for poles from natural forests. To this end, posts of length 10 or 12 meters in a green condition (moisture content > 30%) were stress graded to breakage (Mejia and Escobar, 1984). For the ten posts tested, the maximum fatigue at the point of breakage varied from 287 to 440 kg/cm^2. Before despatch to the treatment plant, *P. patula* poles were stacked and air dried for two weeks for every 2.54 cm of diameter at the thin end (Anon., 1945). Posts of *P. patula* in Colombia are normally 2.5 m in length with an average diameter of 12 cm. The air drying time to a moisture content of 30% was given as 40 days for posts in the climatic conditions of Medellin (Hoheisel and Lopez, 1973). A total of 80 days was needed to reach a minimum moisture content. As the cost of maintaining a stock for 80 days is high, it was suggested that covering the wood storage area as protection from rain would result in more rapid moisture loss. Alternatively, air drying to a moisture content of 30% followed by kiln drying was also suggested as a reasonable combination of cost of drying versus cost of storage area.

Turnbull and Krogh (1939) described a "new" method for testing untreated poles of *P. patula* that were 6.1 m in length. The trees were from South Africa (no age given) and it was found that the breaking strain increased from 159 kg to 682 kg when the pole diameter increased from 8.9 cm to 15.2 cm. Donald (1983) found that fertilization and thinning of 9.5 year old *P. patula* in South Africa would result in more trees that would attain the sizes required for poles or posts. Nine years after fertilization and thinning, the return on investment was 26%.

With appropriate treatment, *P. patula* should be suitable for poles and posts. The species will succeed in this use if the trees have been allowed to attain a certain age (minimum 15-20 years) prior to felling; it is critical that bottom log is used for poles. More recent reports on actual usage would be helpful. There is a need for more genetic and silvicultural effort to obtain more uniform posts and poles, or this market is likely to be taken by cement, plastics or metal products.

12. Sawmill Products

For house and building construction there is a need to develop uniform wood products from sustainable sources. *P. patula* has proved to be an ideal timber for construction in South Africa. Information concerning lumber strength and variation should allow further development of the species for these high value products.

12.1 Recovery

Paterson (1963) evaluated average recovery in structural grades from *P. patula* in Kenya. As tree age increased from 12 to 35 years the total lumber recovery increased from 37% to 52%. Recovery of structural grades (clears, firsts and seconds) increased from 23% at age 12 years to 41% at age 35 years (Paterson, 1965). Paterson (1966a,b) reported the recovery of lumber as 30% for logs from 12 year old thinnings while this improved to 50 to 60% for 35 year old clear fellings in Kenya. When logs of 30.5 cm were processed, recovery was 70% or more (Burghers, 1972).

Howland and Paterson (1971) studied recovery from *P. patula* from Dedza Mountain, Malawi. Lumber recovery was 47%, with 33% as Grade I. Recovery from the first 7 m log was 51% while for the fourth 7 m log it was 34%.

12.2 Drying and Shrinkage

Some of the reasons for wood drying are to reduce the weight of the product, prevent discolouration (blue staining), increase durability and enhance strength, paintability and workability. It is very important to control shrinkage during drying in the processing of round stems to sawn lumber. The drying methods (kiln or air) can be managed in order to develop an end product with the moisture content required by the end users. Reports of lumber shrinkage in *P. patula* are summarized in Table 7.

Table 7. Lumber shrinkage (%) of *P. patula* from various locations. Shrinkage can be volumetric (V), longitudinal (L), tangential (T) or radial (R). Moisture content (MC) is reported where specified.

Reference	Location	Age (yrs)	Shrinkage (%)	Comments
Anon., 1940	South Africa	-	L 0.2	air dried
Anon., 1980	Colombia	-	V 12.1	129% to 0% MC
Anon., 1982	Colombia	-	V 5.66 V 12.2	green-12% MC green-0% MC
Barcenas, 1985	Mexico	-	V 10.6, R 6.2, T 9.7	12% MC
Chimelo, 1992	Brazil	-	V 11.8, R 3.8, T 7.2	
Escobar and Uribe, 1970	Colombia	-	V 5.7 V 4.4	air dried oven dry
Gueneau, 1970	Madagascar	-	V 12.8, R 2.6, T 7.7 V 15.0, R 3.8, T 9.9	455 kg/m^3 517 kg/m^3
Lastra, 1986	Colombia	-	V 8.0	15% to 0% MC
Orman, 1952	New Zealand	37 45	V 10.8, L 0.3, T 6.9, R 3.7 V 10.4, L 0.6, T 6.5, R 4.1	green-0% MC green-0% MC
Plumptre, 1969	Uganda	-	R 2.8 T 3.7	green-12% MC green-12% MC
Quinones, 1974	Mexico	-	V 2.0, R 2.6, T 4.8 V 2.4, R 1.7, T 4.1 V 3.6, R 2.8, T 5.4	12% MC 12% MC
Scott, 1949	South Africa	-	R 3.5	
Van Vuren *et al.*, 1978	South Africa	-	V 9.7	128%-0% MC

Paterson and Howland (1971) determined the sample sizes required to accurately estimate shrinkage for *P. patula* in Malawi. Six samples of the larger size (2.5 x 7.5 x 15.0 cm) or twelve samples of the smaller size (0.68 x 1.88 x 3.75 cm) gave equal estimates of shrinkage.

Stohr (1980) found that *P. patula* had higher moisture content as one went from a stem height of 0.3 m to 12.3 m. However, the difference in moisture content between 14 year old trees and 21 year old trees was small (162.3% versus 166.0%). Banks and Schwegmann (1957) compared the shrinkage properties in disks taken at a height of 6.1 m from trees of *P. patula* grown in South Africa at Tweefontein (19 years) and Weza (22 years). The initial moisture content was similar as was volumetric shrinkage. The radial and tangential shrinkage was slightly higher for the trees from Tweefontein. Turnbull (1940) sampled 25 year old *P. patula* from Cedara, Natal, South Africa. The author found a close inverse relationship between longitudinal and transverse shrinkage and suggested that this was due to fibril angle.

The rate of air drying in Malawi is faster when using stickers that are 5.0 cm in diameter rather than the normal thickness of 2.54 cm (Howland, 1971). However, the quantity of wood that can be placed in the stack will be reduced. Green lumber required an average of 9.2 weeks to reach a moisture content of 15% using the larger stickers. Mortenson and Paterson (1968) estimated losses from air drying without restraint to be 40% in *P. patula* and recommended that all timber be dried under restraint. It has been found that twist was twice as much at a moisture content of 11% to 12% than at 16% (Anon., 1960a).

Scott (1945, 1948) gave detailed reports of wood seasoning in South Africa. For green wood of *P. patula*, a moisture content of 200% was given as the average. For air drying under climatic conditions at the highveld in South Africa, boards of 2.7 cm thickness require 28 days and boards of 5.4 cm thickness require 90 days to reach a moisture content of 13%. Posts of 22.9 cm diameter had reached a moisture content of 20% after seven months of air drying. The author concluded that air or kiln drying of *P. patula* was very easy but that drying tended to be uneven and that rapid conversion was needed to avoid problems with blue staining.

Scott (1953) suggested that South African *P. patula* boards of 2.54 cm thickness could be kiln dried in 4 to 5 days, followed by air seasoning of five weeks. When *P. patula* boards with a thickness of 3.8 cm were dried at 95^{0}C the time required was 50% less than that when dried at 50^{0}C (Anon., 1971). It was reported that less power was consumed in the higher temperature drying regime. When air dried boards of *P. patula* were moistened and then air dried again, the amount of twist originally present was doubled (Anon., 1960b). If the boards were straight grained there was no change from air-dry to moist to air-dry condition. This characteristic would be important for any outdoor use.

Kiln dried lumber of *P. patula* was 39% lower in twist when restraint of 19,200 Newtons was used during drying (Tischler et al, 1979a,b). Lumber dried using restraint also had lower average values in bow, spring and linear shrinkage. Bester *et al.* (1979) found that putting pith free boards in the top 7 layers of the stack, with no mechanical restraint, can reduce the presence of twist. However, the authors concluded that mechanical restraint was more effective, although more costly.

Kiln drying of *P. patula* was easier when logs were sprinkler irrigated with 75 mm of water per day (von dem Bussche, 1993). The improvement was said to result from a more uniform moisture content. The quality of the dried planks was better due to the absence of surface checks and other drying defects.

Vermaas and Wagner (1983) reported that modulus of elasticity, work to maximum load and modulus of rupture were reduced for *P. patula* lumber dried at 130 ^{0}C relative to 110 ^{0}C. Energy consumption by drying kilns was costly (40 to 70% of total energy consumed) as was inefficient use of kiln space (Vermaas and Wagner, 1983). A model to predict the drying curve of *P. patula* in South Africa was presented by Vermaas (1987). Based on early measures of wood moisture content and the temperature/time factors of the kiln, the model allowed for better utilization and production scheduling. The volumetric change per unit mass moisture change at a moisture content of 10% was discussed by Steinmann and Vermaas (1980).

van Wyk (1963) has observed a large amount of dimensional change and distortion when wood attains an equilibrium moisture content (EMC) in one climate and is subsequently shipped to another climate. For instance, EMC along coastal areas can be 15% in South Africa while more interior locations can have an EMC of 7%. Excessive warp, twist and shrinkage can result once wood has reached the consumer unless the supplier strives to deliver a product with the correct EMC.

Howland and Matawba (1971) evaluated the in-service equilibrium moisture content of *P. patula* in Malawi. The moisture content was 12.1% with a coefficient of variation of 11.0% for a 50 week average under room conditions. Under the conditions of an outdoor verandah, the average moisture content was 14.7% with a coefficient of variation of 15.7%. The authors concluded that kiln drying schedules should take account as to whether the wood is to be used under indoor or outdoor conditions. Wood furniture produced from lumber of *P. patula* varied in moisture content from 8.5% to 12.2% during the course of one year (van Wyk, 1958). This high variation under indoor conditions in South Africa suggested an average moisture content of 10% for seasoned wood for furniture.

Shrinkage during drying can be controlled by better management of kiln or air drying conditions. The use of weights on the top of the drying stack is advisable or losses due to degrade will be incurred. Storage of logs under irrigation should be investigated further. Very little has been published on the subjects of drying and shrinkage during the last 10 years and one speculates whether this is due to proprietary research or due to the unwillingness of journals (trade or academic) to publish these results.

12.3 Lumber Strength, Quality and Uses

One of the difficulties encountered in evaluating lumber strength (Table 8) was that the moisture content was not always reported. As lumber strength normally increases as moisture content is reduced, the lack of moisture content data makes it difficult to compare data across studies. Lumber quality will always be relative to other wood sources available at similar costs. Lumber properties of *P. patula* are summarized in Table 8.

de Villiers (1970) stated that one rapid way to improve lumber quality was to divert all first and second thinnings to the pulpmill. At that time in South Africa, up to 40% of the wood received by sawmills came from thinnings. With the advent of world scale pulp mills in South Africa, one assumes that fewer thinnings now go to sawmills.

Early data from South Africa indicated that the wood of *P. patula* was weak, brittle and soft (Eckbo, 1926; Kotze and Eckbo, 1926), although wood of older trees was expected to have better wood properties. Logs that showed knots were considered unsuitable for timber testing in these early studies. It should be noted that the first plantings of the species in South Africa were in 1907 and the date of planting for this trial was 1914. More recently, de Villiers (1972) stated that timber of the species ranges from excellent to exceedingly poor depending on age and site conditions.

For *P. patula* lumber from South African plantations, Scott (1953) concluded that the wood can be sawn, planed or sandpapered with great ease. However, the wood tended to be ragged when bored or mortised. Strength of the lumber was still increasing at 30 years of age (Anon., 1947) with no correlation between timber strength and rate of growth. For East African conditions, a rotation of at least 35 years was suggested by Paterson (1968c) to maximize value from lumber with better strength properties.

Table 8. Sawmill (lumber) properties of *P. patula* from various locations. The properties are modulus of elasticity (ME, kg/cm^2), modulus of rupture (MR, kg/cm^2), maximum bending strength (MB, kg/cm^2), hardness (H, kg) and compression strength (C, kg/cm^2). Moisture content (MC) is reported where specified.

Reference	Location	Age (yrs)	Property	Comments
Anon., 1980	Colombia	-	ME 86, H 218 ME 110, H 327	97% MC 12% MC
Anon., 1982	Colombia	-	ME 86 ME 100	green 12% MC
Banks, 1970	South Africa	30	MB 812, C 343 MB 651, C 259	low altitude high altitude
Banks, 1977	South Africa	-	MR 740, ME 110	12% MC
Bier, 1983	New Zealand	-	MR 370, ME 61 MR 720, ME 78	green 12% MC
Gueneau, 1970	Madagascar	-	ME 80, H 0.9, C 7.4 ME 110, H 3.3, C 8.6	455 kg/m^3 517 kg/m^3
Lastra, 1986	Colombia	-	ME 97	12% MC
Logie, 1966	Kenya	15 30	MB 499, ME 70 MB 735, ME 114	
Ordonez *et al.*, 1989	Mexico	-	MR 468, ME 92 MR 933, ME 117	green 12% MC
Otto and van Vuren, 1976	South Africa	-	MR 730, ME 110	12% MC
Sekhar *et al.*, 1974	India	-	MR 297, ME 26	113% MC
Shukla and Sangal, 1986	India	9	MR 269, ME 39, H 121	128% MC
Turnbull, 1937	South Africa	21	MR 529 MR 896	interior 16 cm exterior 16 cm
White *et al.*, 1980	Tanzania	12	MR 810, ME 98	

It is interesting to note that Craib (1939) concluded that rate of growth did not affect lumber strength in *P. patula.* As silviculture has undoubtedly led to further increases in growth rate, it would be informative to know if a similar comment could be made today. de Villiers (1970) stated that most wood technologists maintain that 4 to 6 growth rings per 2.54 cm of radius are required to produce timber of acceptable strength.

Five trees from stands at 19 years (1,660 m elevation) and 22 years (2,380 m elevation) in Meru Forest Project, Tanzania, were tested for strength properties (White *et al.*, 1980). There were no significant differences in strength properties of wood from the two sites.

Gerischer *et al.* (1976) reported an assessment of the effect of wind damage on the material originated from Weza, South Africa, in plantations that were 18 to 20 years of age. While the wood was similar in moisture content and wood density, there were large differences in lumber strength. Modulus of elasticity was 34.0% higher in lumber from undamaged trees, and modulus of rupture was 51.4% higher.

For South African *P. patula*, Turnbull (1937) stated that a log of 45.7 cm diameter will have less than 10% of the cross sectional area in the "weak core". de Villiers (1974) suggested that boards from the centre of the log be sawn into widths of 2.54 cm to facilitate rapid drying and ease of restraint therefore assuring a reduction in twist.

The lumber strength of *P. patula* in Mexico has been evaluated by Quinones (1974). The lumber strength properties were higher for wood at 12% moisture content than for wood with moisture content of 100% or greater. For the three sites included (Pueblo, Hidalgo and Veracruz), variation at 12% moisture content was reported for modulus of elasticity (1379, 1364 and 1532 kg/cm^2), force of rupture (1003, 961 and 1070 kg/cm^2) and force at proportional limit (685, 611 and 744 kg/cm^2).

Lumber strength properties of *P. patula* at an age of 26 to 28 years from Malawi were reported by Paterson (1971a). From each of seven trees, the centre flitch from the 6.5 m butt log was cut to a thickness of 5.1 cm. The test sticks were removed at 1 m intervals up the centre flitch and at 5.1 cm intervals from the pith. At a moisture content of 12%, the modulus of rupture was 850 kg/cm^2 while the shear strength parallel to the grain was 1.370 kg/m^3. Other pine species included in this trial were superior to *P. patula* in these characteristics.

The stress grading (modulus of elasticity) of lumber from *P. patula* in Malawi was evaluated by Paterson (1971b). He concluded that the timber could be marketed in three grades (42, 60 and 84 kg/cm^2); the SABS (South African Bureau of Standards) visual merchantable grade met the 60 kg/cm^2 stress grade. The SABS specified a minimum wood density of 400 kg/m^3 at a moisture content of 15% for structural timber (Sherry, 1967).

For East African grown *P. patula*, wood density correlated significantly with all green and dry lumber strengths (Paterson and Campbell, 1970). The authors recommended that a 15 cm square block be boxed (sawn) out from the centre of the tree, to remove weak wood near the pith.

A study of *P. patula* lumber from Uganda revealed that the mean compression strength of the "best" tree was 1.44 times greater than that of the "worst" tree (Plumptre, 1978). Small clear specimens of *P. patula* wood from Yarraman, Queensland, Australia, were tested for static bending (Siemon, 1979). The modulus of rupture was 81.3 and the modulus of elasticity was

9,305 for samples from 39 year old trees with a wood density of 490 kg/m^3. The coefficient of variation was much higher for modulus of rupture (19.7%) and modulus of elasticity (23.1%) than for wood density (12.2%).

An attempt to facilitate the rapid measurement of strength of structural timber uses the piezoelectric effect (Knuffel *et al.*, 1986). A stresswave is created by hitting a board with a flat-faced cam-driven pendulum hammer. The resulting piezoelectric excitation is then measured. Structural testing of lumber in this manner is as fast as that using conventional stress grading machines. Further work on this promising technique with *P. patula* was described by Knuffel (1988a,b).

Strength reduction due to spiral grain of *P. patula* in Colombia was studied by Arango (1989), where boards with a grain angle greater than 7.7^0 are not acceptable for structural use. From trees with a minimum diameter of 30 cm, boards from the centre of the tree were prepared for grain angle measurement and stress grading. In terms of modulus of elasticity, boards of acceptable strength could be derived when the grain angle was 10^0 or less. However, to meet force of proportional limit criteria, a grain angle of 0^0 was needed.

A detailed consideration of the cellular components of lumber strength in *P. patula* was given by Bariska (1985). The load carrying zone is the latewood lamellae and the weakest zone tends to be the second row in the earlywood at the growth ring boundary. However, earlywood can stop the spread of failure in compression since excessive stresses were dissipated by easily induced deformations.

de Villiers and Perry (1973) and Banks (1977) indicated that heavy pine flooring (minimum wood density of 550 kg/m^3) could be made from South African *P. patula* wood originating from the outside growth areas of trees more than 20 years old. Lewis (1964) felt that *P. patula* timber would be adequate for "all general purposes" by the age of 30 years. Grut (1965) reported that the wood of young trees was suitable for the production of box shoots while wood from older trees could be used for constructional purposes. However, Lamprecht (1989) stated that wood of the species was seldom used for furniture.

The use of wood of *P. patula* for treated wood shingles was at one time under study in South Africa. Scott (1951) reported that wood shingles of *P. patula* withstood a very severe hailstorm in Pretoria, South Africa. The shingles had been in use for 11 years and were superior to those of other tree species. It was suggested that future shingles be of a thickness from 1.42 cm to 1.59 cm.

Testing of *P. patula* from Cofre de Perote, Veracruz, Mexico, led to the conclusion that the wood had dimensional stability (Sotelo *et al.*, 1978). For the trees tested, the recommendation was that the lumber could be used where high mechanical resistance was needed.

The resistance in lumber to the withdrawal of nails is important in construction, pallet manufacture and other uses. In Australia, Reardon and Boughton (1984) reported that other conifer species gave better resistance than *P. patula* to nail withdrawal. They found no correlation between withdrawal resistance and wood density. Wood of *P. patula* from lower altitude in South Africa (Tzaneen) was more difficult to nail than wood grown at higher altitudes (Ermelo, Lothair and Belfast), presumably due to higher wood density at sites of lower altitude (de Villiers, 1965).

The use of sawn wood of *P. patula* in Tanzania for pipes, water tanks and road culverts was discussed in detail by Lipangile (1990). The author considered pine wood suitable for woodstave pipes due to the high bending stress of the wood and the ability to be pressure treated. In fact, Lipangile (1990) stated that pine wood used for such purposes could be 4 to 12 times cheaper than the same products made from plastic, concrete or steel.

12.4 Grading

Damage to the stems of *P. patula* during logging could reduce potential sawmill yield by 11% (Paterson, 1970). Resawing of seasoned *P. patula* wood from Malawi was studied by Howland and Paterson (1969), who found the loss in degrade was 48% by volume and 16% by value. The authors concluded that for construction grade material the best mill practice was to cut sizes for the predicted market rather than cutting larger sizes for resawing to order.

Stohr (1977) listed twist as the major degrading feature of *P. patula* in the seasoning process. He suggested drying at higher temperatures and with heavy restraint of the lumber, and concluded that twist results when juvenile wood was included in the lumber. For economic reasons, logs of larger diameter class (27 to 36 cm) should be preferred to those of smaller diameter class (17 to 23 cm). de Villiers (1966) reported a 30% loss due to degrade for twist in sawing for lumber of logs of *P. patula* with a top diameter of 17.8 to 19.1 cm. van der Merwe (1973a,b) stated that twist is higher in boards which have the presence of pith. Drying at higher temperatures and under restraint can reduce twist.

The degrade from *P. patula* in Malawi (Howland and Patterson, 1971) was largely due to knots (40%) and twist (22%). Twist was associated with whole tree grain angle and density gradient from pith to bark.

Overall, recovery, strength and quality of sawn lumber were higher for older trees or for boards that were from the outer part of the stem. Silviculture and genetics could have a profound effect on lumber quality and strength if managers were willing to make the required implementations. For most purposes, including structural, decorative and furniture, *P. patula* is of adequate quality, especially as stocks of native timber are being reduced in those countries where the species can be grown.

13. Veneer and Plywood

A small juvenile core is desirable for veneer and plywood. However, veneer made from juvenile wood in *P. patula* had a rough surface and an uneven thickness (Burgers, 1972). In addition, the core could split during processing. Planting trees at closer spacing will reduce the size of this juvenile core and the size of the tree unless thinning is implemented early in the life of the stand.

For plywood production, de Villiers (1974) indicated that it was almost impossible to peel *P. patula* to a core diameter of less than 13 cm. Veneers which included wide areas of earlywood with higher moisture content caused drying to be uneven. Kromhout and Bosman (1981) found the yield of veneer from a round log to vary between 45% and 50%; most of the pine veneer will be used as ungraded core material.

The use of *P. patula* for plywood in Colombia has been studied by Velez (1984). The best adhesive in the study was urea-formaldehyde and the species presented no difficulties in plywood production. Compared to lumber, plywood was more stable and was stronger for the characteristic of modulus of elasticity.

14. Pulp and Paper-making Characteristics

It can be stated with confidence that more wood of *P. patula* is being processed for pulp and paper than for any other use of the species. Compared to species from north temperate regions, however, there is a lack of published information for *P. patula*. In a number of countries, the use of *P. patula* for pulp and paper-making should be further evaluated on a commercial basis.

14.1 Chemical and Semi-Chemical Processes

Two publications from FAO (1980a,b) gave data concerning numerous pulping trials of *P. patula*. For sulphate cooks in the normal range of active alkali, yield was average. The strength, especially tear index, was very high and resembled pine pulps from the southern United States. NSSC pulps of *P. patula* from Madagascar had unacceptably low values for pulp strength. Some of the most extensive studies of *P. patula* chemical pulping are those of Mr. Ted Palmer, as reported variously from the Tropical Products Institute, Tropical Development and Research Institute and Overseas Development Natural Resources Institute (Palmer, 1985, 1987).

Following initial results of pulping wood of *P. patula* in South Africa with the soda process, the sulphate process was evaluated (Loseby, 1935). The author reported that "no special difficulties would be encountered in treating the wood on a commercial scale". These comments proved rather prophetic, considering that today South Africa has two of the largest pulp and paper-making enterprises in the world and they rely for much of their long fibre material on *P. patula*.

The first usage of *P. patula* for pulp and paper in South Africa was at the Premier Paper Mill, Johannesburg (Loseby, 1939). The plan was to use cereal straw and pine wood for a 14,000 ton per year mill.

From a sulphate pulping study comparing *P. patula* trees that were fast- or slow-grown from Viphya Plateau, Malawi, Palmer and Gibbs (1974) concluded "there was no clear relationship between site and age of wood with digestion conditions, pulp yield and delignification or pulp strength characteristics". As the active alkali concentration increased, kappa number decreased, though there was also a decrease in the handsheet strength properties of burst factor, breaking length, stretch and tear factor. Using a three stage bleaching sequence (chlorination, alkali extraction and hypochlorite), there was a loss in yield of 10% of the unbleached pulp.

Three pulp samples were evaluated (sulphate process) for *P. patula* from Sao Hill, Tanzania, by Palmer *et al.* (1984). Pulp yield was slightly lower for wood from 6 year old trees than from trees of 10 or 14 years. For the ages tested, the tensile index and burst index were very similar for the refining levels evaluated. Tear index was higher for pulp from the older trees while tensile energy absorption was lower for wood from older trees. In terms of bleaching, pulps from the older trees consumed less chlorine. The bleached pulps showed higher values for the indices of burst, tear and tensile as the age of the wood increased.

Results of sulphate pulping studies of wood of *P. patula* from Tanzania, at ages 6, 10 and 14 years, were reported by Palmer *et al.* (1984). The screened pulp yield averaged 48% at a kappa number of 47, while the screened pulp yield in bleachable grade averaged 44% at kappa number 25. Bleached pulps were lower in burst and tensile strength (1-2%) and in tearing strength (4-6%) than unbleached pulps. For unbleached pulps, tearing strength was more than 40% higher for pulps from the 14 year old sample than for those of the 6 year old sample. The younger samples were slightly higher for bursting strength (6.73 cf. 6.33) for unbleached pulp. In bleached pulp, a similar trend was observed for tearing strength but an opposite trend for bursting strength. At a CSF of 500, the bursting strength of 6 year old pulps was 5.76 compared to a value of 6.38 for pulps from 14 year old trees. This result may indicate more fibre wall degradation in pulp from younger trees subjected to bleaching conditions.

Chikamai (1987a,b) evaluated the kraft pulping properties of Kenyan-grown *P. patula* at ages varying from 12 to 18 years. Pulp yield was similar for the ages tested. However, tear index increased as the age of the wood sample increased, while burst index decreased. The author found that to reach a CSF of 500, the pulps from 12 year old trees needed 39 minutes of refining compared to 49 minutes for 18 year old trees.

Trees of *P. patula* from about 2,000 m altitude in Kenya, and ranging in age from 10 to 20 years, were evaluated for chemical pulping (sulphate) by Palmer *et al.* (1982b). All of the samples yielded an average screened pulp yield of 47% at a kappa number of 40. Pulp of kappa number 30 was higher for tear index while pulp of kappa number 40 was higher for tensile and bursting strengths. Tear strength was 50% higher for pulp from 20 year old trees in comparison to that from 10 year old trees, though tensile and bursting strengths were 10% to 15% lower for the older material. At a kappa number of 20.7, the total chlorine consumption for bleaching was 8.1% while the figure was 10.6% at kappa number 30. Bleached pulps were slightly lower in strength relative to unbleached pulps.

Two logs of 10 year old *P. patula* from Sabie, South Africa, gave a pulp yield of 45.8 % at a kappa number of 35 (du Plooy and Venter, 1981). Tear and tensile indices decreased with refining while burst index increased as the pulp was more heavily beaten.

Sharma *et al.* (1984) evaluated ten year old *P. patula* from Uttar Pradesh, India, for kraft pulping conditions. At kappa number 94.9 the total pulp yield was 48.9%, while at kappa number 30.0 the value was 36.0%. They found that higher pulp yield could be obtained by cooking at higher temperatures or by a higher percentage of active alkali, though kappa number would also increase. No relationship could be established between paper strength and pulping conditions with higher temperature or higher active alkali. However, with refining, there was an increase in stretch and the indices of tensile and burst while that of tear decreased.

Five trees of *P. patula* aged 10.5 years from South Africa were pulped individually (Wright and Wessels, 1992). The authors reported that pulp yield for individual trees varied from 45.79% to 48.26%, while kappa number varied from 55.5 to 62.8. Following refining, handsheet properties varied for burst index (6.9 to 7.8), tear index (10.9 to 13.9) and breaking length (6331 to 7919). They suggested evaluating individual trees for pulping properties before including them in a tree breeding programme.

Neutral sulphite (semi-alkaline sulphite) pulping conditions were imposed on *P. patula* at age 10-11 years from Zimbabwe (Thornton, 1988). The cooking time was 45-75 minutes at 180°C with a 4:1 sulphite to carbonate ratio and 0.1% anthraquinone (AQ) on bone dry wood. The pulp yield was 70%. This pine pulp could be incorporated at 10% of machine furnish for unbleached kraft linerboard with no change in strength.

Palmer and Ganguli (1988) took a single full-sib family of *P. patula* at age twelve years grown on five sites in Zimbabwe for chemical pulp (sulphate) evaluation. Four trees were sampled at each site and the sites varied in altitude from 700 m to 2135 m. Trees from the lowest altitude site (Chiwengwa) had more resin and lower pulp yield. There were significant differences between sites for pulp yield and lignin content. The site with the lowest rainfall (Grasslands) yielded pulps with the highest tear index.

Du Plooy (1982a) evaluated alkaline and semialkaline sulphate pulping of 15 year old *Pinus patula* from South Africa. Alkaline sulphate pulp prepared with AQ at a yield of 60% had average strength values compared to kraft pulp at a yield of 47.5% with a kappa number of 45. Semialkaline sulphite cooking (Na carbonate buffer and AQ) with a temperature of 178-180^{0}C gave pulp of the same quality in the same time as would alkaline sulphite pulping at 175^{0}C or kraft pulping at 170^0.

For seventeen year old *P. patula* from the Eastern Transvaal, South Africa (Robertson, 1991), the screened pulp yield was 43.5 at kappa number 30.5 using sulphate cooking conditions. After 350 counter revolutions in a PFI refiner, the tear index was 13.7 while the burst index was 6.3.

Chemical pulping trials were conducted for *P. patula* at age 17 years from Natal, South Africa (Wright and Sluis-Cremer, 1992). Pulping results from 13 trees processed individually gave mean values (range) of 45.7 (37. to 55.4) for kappa number, 46.7% (42.0% to 51.2%) for pulp yield, 5.44 (4.61 to 6.52) for burst index and 13.44 (9.8 to 16.2) for tear index. The nature of variation between trees in terms of pulp and paper-making properties deserves further research in order to include these considerations into tree breeding programmes and silvicultural management.

For wood of *P. patula* from Kenya (Anon., 1962), the screened pulp yield varied from 46.4% to 55.6% for different timber types at chemical pulping conditions of 25% sulphidity, 17.5% active alkali, maximum temperature of 170^{0}C for three hours and one hour to temperature. As refining time in a valley beater increased, the values of burst factor, breaking length and stretch increased while C.S.F. and tear factor decreased.

For wood of *P. patula* from Kenya (Anon., 1962), the screened pulp yield varied from 62.8 to 70.8 for different timber types at semi-chemical pulping conditions of 25% sulphidity, 7.5% active alkali, maximum temperature of 170^{0}C for 1.75 hours and 0.75 hours to temperature. All of the semi-chemical pulps were very dark in colour and it was considered that bleaching would not be economic.

For chemical pulping of *P. patula* in Madagascar, Tissot (1968) obtained a pulp yield of 50.8% at a permanganate number of 18.5. The breaking length of paper derived from this pulp was 6,300 with a stretch of 2.2%. Pulping conditions of *P. patula* from Madagascar were also evaluated by Petroff *et al.* (1968). As NaOH levels increased from 18% to 26%, pulp yield decreased from 49.1% to 45.7%. Permanganate numbers were 35 and 18.5 for NaOH levels of 18% and 26%, respectively. The cooking conditions were 60 minutes to a temperature of 120^0, 60 minutes to 170^0, and 90 minutes at 170^0.

Petroff (1968) reported that an Angolan pulp mill (Cellulose do Ultramar Portugues) was using *P. patula* as a raw material. The wood (age not given) was reported to have a yield of 42% to 46% when pulped at 20% to 23% Na_2O with a temperature of 165^0 (time not given) and a delignification (MnO_4K) of 16 to 22.

P. patula has acceptable growth rates on well drained fertile soils in New Zealand (Uprichard and Gray, 1973). When the authors conducted a pulping study of 25 year old material at a kappa number of 34, they obtained a pulp yield of 48.7%. They concluded that the species had high tear factor, even after beating for 8,000 revolutions in a PFI mill.

Uprichard (1970) sampled five trees of *P. patula* at an age of 28 years from Rotoehu Forest, New Zealand, for their kraft pulping characteristics (sulphidity of 24%, 14% to 18% Na_2O, maximum temperature of 170^0C for 1.5 hours). At a kappa number of 22 the total pulp yield was 48.2%, while the corresponding figure at kappa number 59 was 51.8%. When refined in a PFI mill (10% stock concentration) the resulting hand-sheets were reported to have "relatively high tear factor but only moderate burst factor and tensile strength".

In a further test of *P. patula* from New Zealand, Hinds (1968) reported chemical pulping results. For kappa numbers ranging from 22 to 45, the resulting screened pulp yields were 46% to 49%. The species was said to be satisfactory for a commercial operation. In a brief examination (Uprichard, 1970) of bisulphite pulping (18% to 20% $NaHSO_3$, 3.5 hours at maximum temperature of 170^0C, 1 to 2 hours to maximum temperature) the total pulp yield at kappa number 22 was 48.2% while at kappa number 93 the value was 59.1%. Hand sheets made from these New Zealand pulps were lower for tear index and burst index than for hand sheets from the kraft pulps.

India is a country with less than 6% of the forest area under conifers, and efforts to establish plantations of tropical conifers have been underway for many decades. Sulphate cooking of ten year old *P. patula* from Uttar Pradesh, India, was undertaken by Sharma *et al.* (1987). The authors reported total pulp yield to be 46.0% at kappa number 30.7 and 50.3% at kappa number 34.6.

A pilot plant trial of *P. patula* kraft pulping was conducted by Guha *et al.* (1976) on trees from Darjeeling, West Bengal. At a kappa number of 27, the unbleached screened pulp yield was 45.1%. Cooking conditions were 25% sulphidity, 20% active alkali, total time of 4 hours at a final temperature of 170^0C.

Moorthy *et al.* (1977) evaluated *P. patula* as a potential raw material for paper making (kraft process) for Panafrican Paper Mills, Broderick Falls, Kenya. The authors concluded that the species gave pulps with high stretch, burst and tear that would make them suitable for good quality sack kraft papers. They stated that normal chemical recovery from the black liquor could be expected.

Chemical pulping results from South African grown *P. patula* have been given by Palmer *et al.* (1984). The screened pulp yield was 43.7% at kappa number 35 and 41.6% at kappa number 27.8. At a CSF of 500, the tear index was slightly higher from pulps with higher kappa number (13.3 to 12.6) though it was not reported whether this was statistically significant. A trend of higher burst index (6.85 to 6.25) at higher kappa number was also observed.

The pulping properties (sulphate process) of *P. patula* from Malawi were evaluated by Eklund *et al.* (1974). The authors concluded that bleached pulps were almost equal to Scandinavian pine pulps and were superior for tear strength. The pulping conditions for *P. patula* at Usutu Pulp, Swaziland, were described by Dubois (1966). In that study, it was concluded that wood accounted for 32% of the total cost of pulp production.

Saenz (1991) informed the author that wood of *P. patula* was being utilized for pulp in Mexico at Fabrica de Papel (Tuxtepec, Oaxaca) and Papelera San Rafael (Estado de Mexico). Campos (1990) also stated that the species is used for pulp and paper in Oaxaca, Mexico.

Sappi Pty Ltd (South Africa) have published various chemical pulping results with *P. patula* (Anon., 1992). As refining in a PFI mill increased from 0 to 18,000 revolutions, there was an increase in burst index (3.5 to 5.9), an increase in breaking length (5,183 to 10,116) and a decrease in tear index (20.2 to 11.2). With a wood density of 421 kg/m^3, kraft pulping to a kappa number of 73.34 gave a pulp yield of 49.85 with a tear index of 14.1 at burst index of 5.5.

de Plooy (1978) compared the pulp and hand sheet properties for debarked logs and for the whole tree of 15 year old *P. patula.* The whole tree sample consisted of bark, roots and all of the above ground biomass except for the needles. The whole tree sample resulted in 40% more pulp and gave hand sheet strength properties that were 95% of those obtained from the debarked log.

The sulphate pulping quality of *P. patula* sawdust from South Africa was investigated by Venter (1974). Pulp yields varied from 35 to 49% for kraft pulping conditions of 22% active alkali, 21% sulphidity, 90 minute to temperature and 60, 90 or 120 minutes at temperature (170^{0}C). Strength of the resulting pulp was less than 50% of normal kraft pulp for the species. A small proportion (±10%), however, of pulp from sawdust could be incorporated in regular pulp without significant quality losses.

In the case of Colombia, it was recognized by Bender (1960) that *P. patula* had "exceptional growth" and could substitute for imported pulps of long fibre species. Mih *et al.* (1985) stated that *P. patula* from Colombia responded well to a CEHEH bleaching sequence but could only reach a brightness of 83. The authors found that bleaching reduced paper strength by 20% to 30% relative to unbleached pulps.

Brightness of *P. patula* alkaline and semialkaline sulphite pulps prepared with AQ did not significantly differ from that of CEDED-bleached kraft pulp (du Plooy, 1982b). Sulphite pulps were easier to refine than kraft pulps. The opacity of sulphite pulps was slightly below that of ODED-bleached kraft pulp.

Concern over the use of pulping data of *P. patula* and other species prompted Palmer and Tabb (1968) to state "...it should not be assumed that a wood which is known from the literature or from other sources to give satisfactory or unsatisfactory pulp characteristics when grown in one place will give the same results when grown in another."

An industrial spent liquor from *P. patula* pulped for two hours at 170^{0}C with 18% active alkali and 23% sulphidity to a kappa number of 20 was evaluated by van der Klashorst (1988). The low molecular mass compounds present in acetylated ether and chloroform extract yielded 4.22% based on lignin content.

The chemical pulp and paper-making properties of *P. patula* are excellent, though semi-chemical pulps would seem to be less desirable. Across the range of sites planted, the species has been subject to the greatest utilization for paper-making of any planted conifer in the tropics and sub-tropics. Only recently have pulping results with individual trees indicated the benefit of developing tree selection and breeding for improved pulp and paper-making traits.

14.2 Mechanical Pulp and Paper-making

The low resin content of *P. patula* was one reason listed by Myburgh and Mackenzie (1966) for the good mechanical pulping qualities of the species. Species with high pitch content make mechanical pulps more costly to process into paper. For mechanical pulping in South Africa, de Villiers (1974) indicated that wood over fifteen years of age was preferred.

Refiner mechanical pulping of *P. patula* at three ages (6, 10, and 14 years) from Tanzania was undertaken using a single disc laboratory refiner (12 inch) operating at atmospheric pressure (Palmer *et al.*, 1984). Pulps from older samples (14 years) had lower drainability than pulps from younger samples (6 years). This indicated that the younger samples consumed more energy in refining. The 14 year old sample yielded pulps with the highest tearing strength. The ISO brightness was about 40 for the unbleached pulps.

Two logs of 10 year old *P. patula* from Sabie, South Africa, were laboratory pulped using the TMP process (du Plooy and Venter, 1981). Comparison at CSF values of 95 and 315 gave differences for several traits including burst index (1.39 cf. 1.01), tear index (4.00 cf. 5.60), tensile index (31.5 cf. 24.3) and TEA (246 cf. 206).

Pilot-plant TMP of *P. patula* from India was said to be very encouraging (Sharma, 1983). Good runnability was found on a pilot newsprint machine. Sharma *et al.* (1984) evaluated 10 year old *P. patula* from Uttar Pradesh, India, for chemi-mechanical pulp. As the CSF value decreased, there was an increase in the indices of tensile and burst.

Gueneau (1970) reported that *P. patula* plantations established in 1950 in Madagascar were being used for mechanical pulping. Mechanical pulp production from *P. patula* totalled 3,000 tons per annum in 1967 (Tissot, 1968). This pulp had a breaking length of 1,730 at a wetness (Schopper Riegler) of 60.

Three pulp samples were evaluated (refiner mechanical pulping) for *P. patula* from Sao Hill, Tanzania (Palmer *et al.*, 1984). At fairly equivalent drainability (CSF of 100 to 120), the tear index was higher when the wood was from older trees. However, the burst index, brightness and opacity did not vary much with the age of the wood.

Sappi Pty Ltd, South Africa, have published various mechanical pulping results with *P. patula* (Anon., 1992; Smith, 1991). Using the stone groundwood process and a CSF value of 140, the tear index was 3.63, burst index was 0.97, pitch % was 1.32 and brightness of 59.7.

One of the most favourable prospects for *P. patula* utilization is for mechanical pulp. The species is the most important for mechanical pulping in the tropics and sub-tropics. Next to North American and Scandinavian producers, *P. patula* must have amongst the highest market acceptability. Should other nations require the inclusion of recycled fibre in newsprint as is the case in the United States, the ability of *P. patula* to accommodate this must be evaluated at manufacturing, printing and marketing levels.

15. Conclusions and Recommendations

It appears that only damaged trees of *P. patula* will produce high levels of resin, although the relatively low resin yield can be increased by paraquat injections. The quality of the resin from the species is not presently as desirable as that of other pines. Where there is sufficient area planted to the species, as in southern Africa, research into increased resin yield, especially the beta-phellandrene component, would make resin production more economically viable.

The determination of certain chemical constituents of wood is much more rapid today than was the case just a few years ago. However, small sample sizes often do not reveal the nature of variation in a product as variable as wood. Lignin and cellulose contents can be determined using near infrared reflectance spectroscopy, which allows for sampling to be undertaken on a large scale. Lignin and cellulose determination could be used to predict potential for end uses such as pulp, reconstituted wood products or charcoal if sufficient data were available.

For *P. patula* plantations grown for pulpwood, the implication of greater cellulose content in mature wood rather than juvenile wood is that longer rotations will be required to obtain higher chemical pulp yields. Reports of evaluations for cellulose yields at differing sites and at different rotation lengths would lead to better forest management as well as improved pulp production.

The fact that most studies do not indicate an adverse relationship between wood density and rate of growth in *P. patula* is very important. This indicates that increases in growth rates due to genetic improvement and to silviculture should not have detrimental effects. However, one speculates as to whether trees grown at very wide spacing in an agroforestry situation would not have lower density due to the free growth under these conditions. The ability to modify wood density through management is an opportunity that goes unrealized simply because managers and researchers do not agree on an ideal wood density for any end use.

The high heritabilities reported for wood density indicate that improvements due to selection and breeding are feasible. Early selection for wood density in the species is very promising possibly as early as age five years, due to the acceptable juvenile-mature correlations for that trait.

Wood density increases radially from the pith though there is a decrease in absolute terms as one samples at increasing heights up the stem. This very predictable age effect on wood density in *P. patula* is used to determine rotation length in some plantation programmes. However, where financial rotations are based exclusively on volume or dry-weight production, there could be a higher proportion of juvenile wood. This will lead to greater lumber degrade, a decrease in pulp yield and a decline in certain paper strength characteristics.

For *P. patula*, there is a lack of information that would allow paper-making properties to be predicted from tracheid dimensions. Given the variation in both radial and tangential directions, the author can not see the value in continued measurements of tracheid dimensions unless acceptable correlations can be derived with paper strength or other end use(s).

Extraction of *P. patula* stems with bark from the growing site will result in a removal of certain nutrients. Whether this removal of nutrients is critical for future use of the site can only be determined by long term experiments. Burning of the bark for fuel at wood processing plants may be less financially attractive if fertilizers must then be applied to maintain site productivity.

Further planting of *P. patula* to reduce the impact of soil erosion should be promoted. At wide spacings this could be followed by animal grazing, once soil conditions have been sufficiently ameliorated. *P. patula* has the capacity to restore agricultural productivity following one rotation (personal observation, Colombia). Biomass yields will affect long term site productivity and reports of these studies should be published as soon as sufficient data are available and analyzed. Research to investigate the sustainable use of the species with animal grazing is required.

Charcoal production with *P. patula* does occur in a number of countries. However, there is a need for this information on charcoal yields and manufacturing techniques to be published. The development of charcoal production from sustainably managed plantations of *P. patula* is suggested for industry, government and non-governmental organizations.

The rapid decay of untreated wood of *P. patula* is consistent across a range of sites. Wood preservation is therefore required if the poles or posts are to be used outdoors for any appreciable length of time. There is a lack of published data on long term field trials with different preservatives. What is especially lacking are field results with preservatives applied in a cold bath manner, which is more likely to be the method used in many less developed countries. Accelerated decay tests could also be used to rapidly evaluate promising wood preservation methods.

The positive developments with reconstituted wood products from *P. patula* should receive more attention at an industrial level. The potential of the species is high, though so are the costs of developing manufacturing facilities and markets for the products.

Greater usage of *P. patula* for posts and poles should be considered. There must be an application of a preservative such as CCA for posts and poles intended for outdoor usage. Higher quality poles and posts will be produced from tree breeding programmes that have placed an emphasis on stem straightness.

The high cost and importance of lumber drying can not be overstated. It is assumed that a great amount of effort has gone into this field of study but there are insufficient recent references. More attention should be given to publishing these results so that research is not duplicated unnecessarily. The possibility of log storage with sprinkler irrigation to reduce blue stain and give a more uniform moisture content of wood at the time of sawing should be considered for further research.

Lumber strength of *P. patula* is adequate for structural timber in the majority of countries where the species is grown. To improve lumber strength, one can process logs of older trees and minimize the use of the interior portion of the log. Correct drying of the boards will increase the most important lumber strength traits of modulus of rupture and modulus of elasticity. Export of dried lumber of *P. patula* does occur and should increase if uniformity can be maintained and marketing strategies well defined.

One area of vast potential for *P. patula* is for veneer production. This is especially true where the species has been thinned and pruned on schedule. However, the technology to produce and use plywood must be in place and this is not the case in many countries where *P. patula* is grown.

The potential of *P. patula* wood for chemical and mechanical pulp and paper-making is well documented. The lack of acceptable results with the semi-chemical pulping is expected since few pine species are used as a raw material for that process. One important characteristic which needs to be evaluated is the bleachable grades that are capable of being produced without chlorine. Certainly this work has been conducted but there were no reports in the literature at the time of writing.

For a number of countries, the use of *P. patula* for pulpwood has reduced the quantity of imported pulp and paper thus conserving foreign capital reserves. Increased paper usage, however, should be accompanied by increased recycling.

The writing and publishing of a compendium such as this was only possible with the open exchange of scientific and other research results. With improved utilization, a smaller area of plantation can sustain an operating facility. The task of sustainable management of plantations of *P. patula* would be made easier if scientists were more willing (or able?) to publish their research findings. As with much of the scientific endeavour, there is concern over vastly different results published for the same trait in different areas. It must be stated that certain publications did not give the units of measure or the moisture content of the wood at the time of testing. Authors and editors should pay more attention to these "details" since comparisons across sites (or benchmarking) on the basis of misinformation can lead to very erroneous conclusions.

References

Anon. (1934) Paper-making trials with coniferous woods from Southern Africa. *Bulletin of the Imperial Institute* **32**: 343-348.

Anon. (1940) Annual Report, Department of Agriculture and Forestry, Pretoria, South Africa, 37 pp.

Anon. (1945) The preparation and preservative treatment of poles. Department of Agriculture and Forestry, Pretoria, South Africa, Bulletin No. 30, 40 pp.

Anon. (1947) Annual Report. Department of Forestry, Pretoria, South Africa, 9 pp.

Anon. (1948) Timber seasoning and utilization. Department of Forestry, Pretoria, South Africa, 7 pp.

Anon. (1949) Specific gravity of *Pinus patula* grown in New Zealand. Annual Report, New Zealand Forest Service, Rotorua, New Zealand, 1948/49, 86 pp.

Anon. (1959) *Pinus patula* Schlechtendal et Chamisso. *Bois et Forêts des Tropiques* **67**: 37-42.

Anon. (1960a) Effect of spiral grain on building timber. Department of Forestry, Pretoria, South Africa, 12 pp.

Anon. (1960b) Timber seasoning. Department of Forestry, Pretoria, South Africa, 16 pp.

Anon. (1962) Report on the examination of plantation softwoods from Kenya as a papermaking material. Report, Tropical Products Institute, London, UK, No. 69/62, 9 pp.

Anon. (1964) Timber quality of *Pinus patula*. Forest Research Institute, Department of Forestry, Pretoria, South Africa, 3 pp.

Anon. (1966) Les plantations de pins a Madagascar et au Cameroun. Centre Technique Forestier Tropical, Nogent-sur-Marne, France, 261 pp.

Anon. (1967) Wood structure and identification: Tracheid length in *Pinus patula*. Department of Forestry, Pretoria, South Africa, 34 pp.

Anon. (1968) Pilot tests of strength properties of some Uganda grown timbers. Uganda Forest Department, Entebbe, Uganda, Timber Leaflet No. 46, 6 pp.

Anon. (1969) Timber mechanics. Annual Report, Department of Forestry, Pretoria, South Africa, 79 pp.

Anon. (1971) Wind damage to standing timber. Annual Report, Department of Forestry, Pretoria, South Africa, 65 pp.

Anon. (1978) Timber from Tanzania. Tanzania Timber Marketing Co. Ltd., Dar es Salaam, Tanzania, 15 pp.

Anon. (1980) Estudio de las propiedades fisicas y mecanicas de las maderas de cipres (*Cupressus lusitanica* Mill.) y pino patula (*Pinus patula*) procedente de la cuenca de Piedras Blancas. Laboratorio de Productos Forestales, Universidad Nacional, Medellin, Colombia, 34 pp.

Anon. (1982) Descripcion de especies: *Pinus patula*. Laboratorio de Productos Forestales, Universidad Nacional, Medellin, Colombia. Madera I: 24-28.

Anon. (1984) Research Review. South African Forestry Research Institute, Pretoria, South Africa, 1983/84, 38 pp.

Anon. (1988) Rapport d'evaluation sur la troisieme etape du reboisement 'plantation'. Projet d'Appui au Reboisement Villageois, Centre Technique Forestier Tropical, Antananarivo, Madagascar, 33 pp.

Anon. (1992) Annual Report. Sappi Forests, Research Division, Howick, South Africa, 45 pp.

Adegbehin, J.O. (1982) Growth and yields of *Pinus patula* in some parts of eastern Africa with particular reference to Sao Hill, Southern Tanzania. *Commonwealth Forestry Review* **61**: 27-32.

Adlard, P.G. (1964) Pruning trial: Dedza mountain forest, Malawi. *Commonwealth Forestry Review* **43**: 238-243.

Adlard, P.G., Bailey, C.G. and Austin, S. (1979) Wood density variation in plantation-grown *Pinus patula* from Viphya Plateau, Malawi. Oxford Forestry Institute, University of Oxford, UK, Occasional Paper No. 5, 15 pp.

Agudelo R., J. and Uribe H., L.G. (1988) Preservacion de estacones de *Pinus patula* con sales de cromo, cobre y boro (CCB) por el metodo de bano caliente y frio. Laboratorio de Productos Forestales, Universidad Nacional, Medellin, Colombia. Madera VII: 28-45.

Aguirre-Bravo, C. and Smith, F.W. (1986) Site index and volume equations for *Pinus patula* in Mexico. *Commonwealth Forestry Review* **65**: 51-60.

Amaral, A.C., Ferreira, M. and do Couto, H.T.Z. (1977) Metodos de avaliacao da densidade basica da madeira de populacoes de pinheiros tropicais. *IPEF* **15**: 47-67.

Arango S., L.G. (1989) Variacion de algunas propiedades mecanicas del *P. patula* Schl et Cham. segun la orientacion del grano. Laboratorio de Productos Forestales, Universidad Nacional, Medellin, Colombia. Madera VIII: 25-39.

Assumpcao, R.M.V. and Jordao, M.C.S. (1983) Qualidade da resina de coniferas. *Silvicultura* **33**: 14-22.

Autio, T. and Miettinen, J.K. (1970) Experiments in Finland on properties of wood polymer combinations. *Forest Products Journal* **20**(3): 36-42.

Bajrang, S. (1982) Nutrient content of standing crop and biological cycling in *Pinus patula* ecosystem. *Forest Ecology and Management* **4**: 317-332.

Banks, C.H. (1956) Effect of nodal swellings on strength properties of *Pinus patula*. *Journal of the South African Forestry Association* **28**: 27-34.

Banks, C.H. (1969) Spiral grain and its effects on the quality of South African timber. *Forestry in South Africa* **10**: 27-33.

Banks, C.H. (1970) The specific strength of South African grown softwoods compared with that of imported Douglas-fir and Scots pine (*Pinus sylvestris*). *Forestry in South Africa* **11**: 27-33.

Banks, C.H. (1977) The mechanical properties of timbers with particular reference to those grown in the Republic of South Africa. Deptartment of Forestry, Pretoria, South Africa, Bulletin No. 48, 88 pp.

Banks, C.H. and Schwegmann, L.M. (1957) The physical properties of fast- and slow-grown *Pinus patula* and *P. taeda* from South African sources. *Journal of the South African Forestry Association* **30**: 44-59.

Barcenas P., G.M. (1985) Recomendaciones para el uso de 80 maderas de acuerdo con su estabilidad dimensional. Instituto Nacional de Investigaciones sobre Recursos Bioticos, Veracruz, Mexico, Nota Tecnica No. 11, 18 pp.

Bariska, M. (1985) Creep and fracture phenomena in wood tissues. In: *Proceedings, Symposium on forest products research international-acheivements and the future.* Pretoria, South Africa, April, 1985. Council for Scientific and Industrial Research, Pretoria, South Africa, Paper No. 16-18, 10 pp.

Bariska, M. and Pizzi, A. (1986) The interaction of polyflavonoid tannins with wood cell-walls. *Holzforschung* **40**: 299-302.

Barnes, R.D. and Mullin, L.J. (1984) *Pinus patula* provenance trials in Zimbabwe - seventh-year results. In: *Provenance and genetic improvement strategies in tropical forest trees.* Mutare, Zimbabwe, April, 1984. (Eds. Barnes, R.D. and Gibson, G.L.). Commonwealth Forestry Institute, Oxford, UK, and Forest Research Centre, Harare, Zimbabwe, 151-152.

Barnes, R.D., Mullin, L.J. and Battle, G. (1992) Genetic control of eighth year traits in *Pinus patula* Schiede and Deppe. *Silvae Genetica* **41**: 318-326.

Barrett, R.L. and Mullin, L.J. (1968) A review of introductions of forest trees in Rhodesia. Rhodesia Forestry Commission, Salisbury, Rhodesia, Research Bulletin No. 1, 227 pp.

Bedel, J. and Rakotovao, G. (1973) Influence de la fertilite du sol sur la qualite du bois. Centre Technique Forestier Tropical, Nogent-sur-Marne, France, 32 pp.

Bedel, J., Rakotovao, G. and Thiel, J. (1975) Experience de preservation de perches et piquets a usage rural en Republique Malgache. *Bois et Forêts des Tropiques* **163**: 55-65.

Bender, W.L. (1960) Raw material prospects for the Colombian paper industry. *Caribbean Forester* **21**(1/2): 21-23.

Beron W., C. and Ramirez de G., M.R. (1985) Evaluacion de resistencia del pino patula (*Pinus patula* Schl and Cham.) y cipres (*Cupressus lusitanica* Mill.) al ataque de termites. Laboratorio de Productos Forestales, Universidad Nacional, Medellin, Colombia. Madera IV: 31-55.

Bester, A.B., Scharfetter, H. and Schuster, H. (1979) Restraint in drying increases revenue from sawn timber. National Timber Research Institute, Pretoria, South Africa. Report No. 62, 4 pp.

Bhartari, S.K. (1986) Biological productivity and nutrient cycling in *Pinus patula* plantations of Darjeeling Hills. *Indian Forester* **112**: 187-201.

Bier, H. (1983) The strength properties of small clear specimens of New Zealand grown timber. Forest Research Institute, Rotorua, New Zealand. Bulletin No. 41, 29 pp.

Birks, J.S. and Barnes, R.D. (1991) Genetic control of wood quality in *Pinus patula*. Final Report, ODA Research Scheme R4616, Oxford Forestry Institute, University of Oxford, UK, 29 pp.

Boden, D.I. (1982) The relationship between timber density of the three major pine species in the Natal Midlands and various site and tree parameters. Annual Report, Wattle Research Institute, University of Natal, Pietermaritzburg, South Africa, 120-126.

Bois, R. du (1966) Une grande usine de pate a papier en Afrique. *Bois et Forêts des Tropiques* **107**: 49-59.

Borota, J. (1991) *Tropical forests: some African and Asian case studies of composition and structure*. Elsevier Science Publishers, Amsterdam, Netherlands, 274 pp.

Bosman, H.L (1967) The practice and economics of using pole pruning-saws in extra high pruning of pines. *South African Forestry Journal* **62**: 23-32.

Brasil, M.A.M., Veiga, R.A.A., Coelho, L.C.C. and Montagna, R.G. (1982) Peso de materia seca da madeira de cinco especies do genero *Pinus* aos 20 anos de idade. ANAIS do 4^0 Congresso Forestal Brasilero, May, 1982, Belo Horizonte, Minas Gerais, Brazil, 739-741.

Bredenkamp, B. (1980) Initial spacing of *Pinus patula* for maximum yield of pulpwood over a 16-year rotation. *South African Forestry Journal* **115**: 47-49.

Brister, G.H. (1960a) A study of variations in tracheid length in *Pinus radiata* and *Pinus patula* grown in Kenya. Special Subject, Imperial Forestry Institute, University of Oxford, UK.

Brister, G.H. (1960b) Tracheid length in *Pinus patula* and *P. radiata*. Annual Report, Imperial Forestry Institute, University of Oxford, UK, 1959/60.

Bryce, J.M. (1967) The commercial timbers of Tanzania. Forestry Division, Ministry of Agriculture, Dar es Salaam, Tanzania, 139 pp.

Burgers, T.F. (1972) Growth prediction for sawlog, pulpwood and veneerlog regimes for *Pinus patula*. *Forestry in South Africa* **13**: 31-44.

Burley, J. (1967) Pine wood studies in Central Africa: I. Introduction, objectives and materials. In: Proceedings of World symposium on man-made forests and their industrial importance. Canberra, Australia, April, 1967. FAO, Rome, Italy. Vol. IV: 2053-2060.

Burley, J., Burrows, P.M., Pattinson, J.V. and Press, A. (1967a) Tracheid length measurement techniques for small wood samples. *Rhodesian, Zambian and Malawian Journal of Agricultural Research* **5**: 289-296.

Burley, J., Press, A. and Morgan, J.F. (1967b) Pine wood quality studies in Central Africa. 2. Development of laboratory techniques. A. Spiral grain. In: Proceedings of IUFRO World Congress, Munich, Germany. Vol. IX: 436-457.

Burley, J. (1973) Variation of wood properties of *Pinus patula* Schiede and Deppe in Malawi. In: Tropical provenance and progeny research and international cooperation. Nairobi, Kenya, October, 1973. (Eds. Burley, J. and Nikles, D.G.). Commonwealth Forestry Institute, Oxford, UK, 574-583.

Burley, J., Adlard, P.G., and Waters, P. (1970a) Variance of tracheid lengths in tropical pines from central Africa. *Wood Science and Technology* **4**: 36-44.

Burley, J., Pattinson, J.V. and Morgan, J.F. (1970b) Wood quality of *Pinus patula* Schiede and Deppe in Central Africa; two trees 45 years old at Stapleford, Rhodesia. *Rhodesian Journal of Agricultural Research* **8**: 131-146.

Burley, J., Mills, W.R. and Morgan, J.F. (1972) Techniques for measurement of latewood in Central African pine timber. *Rhodesian Journal of Agricultural Research* **10**: 169-181.

Bussche, G.H. von dem (1993) Storage of timber under permanent irrigation. *South African Forestry Journal* **164**: 59-64.

Caballero D., M. and Prado O., A. (1969) Observaciones preliminares en una plantacion experimental de *Pinus patula* y *Pinus leiophylla*. Instituto Nacional Investigacion Forestal, Mexico City, Mexico, Boletin Tecnico No. 28, 21 pp.

Cameron, F.A. and Pizzi, A. (1983) CCA-treated laminated pine: the effect of preservative treatment, timber density, type of phenolic adhesive and glue spread on the adhesive bond quality. Council for Scientific and Industrial Research, Pretoria, South Africa, Special Report No. 280.

Cameron, F.A. and Pizzi, A. (1985) Effect of excessive pretreatment of pine timber with CCA wood preservatives on the bond quality of PRF and TRF wood adhesives. *Holz-als-Roh-und-Werkstoff* **43**: 149-151.

Campbell, P.A. (1971) Test on pine and saligna poles. Department of Civil Engineering, University College, Nairobi, Kenya, Occasional Paper No. 5, 6 pp.

Campos D., J.L. (1990) Importancia economica de los pinos Mexicanos. Centro de Genetica Forestal, Chapingo, Mexico, Nota Tecnica No. 5, 6 pp.

Castanos, L.J. (1962) Evaluacion de la calidad de estacion de pino patula en el norte de Oaxaca. Instituto Nacional de Investigacion Forestal, Mexico City, Mexico, Boletin Tecnico No. 2, 28 pp.

Cawse, J.C.L. (1983) Industrial wood regimes for plantations of *P. patula*, *P. taeda* and *P. elliottii*. *South African Forestry Journal* **125**: 35-57.

Cevallos Ferriz, S. and Carmona Valdovinos, T. (1981) Banco de informacion de estudios tecnologicos de maderas que vegetan en Mexico. Instituto Nacional de Investigaciones Forestales, Mexico City, Mexico, Catologo No. 2, 200 pp.

Chikamai, E.N.B. (1986) Wood and kraft pulp quality of plantation grown *P. patula* from Kenya. Unpublished MSc thesis, University of Toronto, Canada. 123 pp.

Chikamai, E.B.N. (1987a) Variation in the wood quality of *Pinus patula* grown in Kenya. *East African Agricultural and Forestry Journal* **52**: 176-183.

Chikamai, E.N.B. (1987b) An evaluation of wood and pulp quality of Kenyan grown *Pinus patula* for kraft papers. *East African Agricultural and Forestry Journal* **53**: 13-18.

Chimelo, J.P. (1992) Propiedades fisicas e mecanicas do *Pinus patula*. Instituto de Pesquisas Tecnologicas, Divisao de Maderias, Sao Paulo, Brazil, 1 pp.

Chudnoff, M. (1980) *Tropical Timbers of the World*. Forest Products Laboratory, Madison, Wisconsin, USA, 831 pp.

Cittadini, A. (1942) Behaviour of some South African woods on pulping by the Pomilio process. *Osterreichische Chemiker-Zeitung* **45**: 193-201.

Coetzee, P.F. and Quinn, P. (1978) Service tests with Busan 30, Difolatan and sodium pentachlorophenate/borax pentahydrate as sapstain preventatives. *Wood, Southern Africa* **3**(8): 13-14.

Conradie, W.E. (1985) CCA treated laminated railway sleepers and telephone cross-arms. *South African Forestry Journal* **133**: 33-39.

Conradie, W.E. and Pizzi, A. (1985) A new ground-contact wide-spectrum organic wood preservative: DNBP. *Holzforschung-und-Holzverwertung* **37**(3): 50-57.

Conradie, W.E. and Pizzi, A. (1987a) Waterborne DNDP wood preservatives-preparation and performance. *Holzforschung-und-Holzverwertung* **39**(2): 21-24.

Conradie, W.E. and Pizzi, A. (1987b) Progressive heat-inactivation of CCA biological performance. *Holzforschung-und-Holzverwertung* **39**(3): 70-77.

Conradie, W.E., Pizzi, A. and Jansen, A. (1985) The penetration characteristics of CCA preservatives in wood. In: Proceedings, Symposium on forest products research international-achievements and the future. Pretoria, South Africa, April, 1985. Council for Scientific and Industrial Research, Pretoria, South Africa, Paper No. 4-10, 16 pp.

Coppen, J.J.W. (1991) A walk in the forest: first steps in the evaluation of pine resin as a source of aroma chemicals. In: The chemistry of flavours and fragrances - the natural/nature identical challenge. University of Kent, Canterbury, UK, July, 1991.

Coppen, J.J.W., Robinson, J.M. and Mullin, L.J. (1988) Composition of xylem resin from five Mexican and Central American *Pinus* species growing in Zimbabwe. *Phytochemistry* **27**: 1731-1734.

Cordoba, A. (1985) Predicting growth and yield for *P. patula* plantations: a case study from Colombia. Smurfit Carton de Colombia, Cali, Colombia, Research Report No. 101, 16 pp.

Correa Calderon, N.A. (1988) Variaciones en peso especifico de *Pinus patula* Schl. et Cham. con altura, diametro, edad y crecimiento. *Cronica Forestal y del Medio Ambiente* **5**: 1-12.

Craib, I.J. (1939) Thinning, pruning and management studies on the main exotic conifers grown in South Africa. Department of Agriculture and Forestry, Pretoria, South Africa, Science Bulletin No. 196, 179 pp.

Crowe, N.D. (1967) Growth, yield and economics of *Pinus patula* in the Natal Midlands. Annal, University of Stellenbosch, South Africa, Serie A (2), No. 42, 82 pp.

Cummins, N.H.O. (1972) Heartwood differentiation in *Pinus* species - a modified azo-dye test. *New Zealand Journal of Forest Science* **2**: 188-191.

Davis, C.L., Hinch, S.A., Donkin, C.J. and Germishuizen, P.J. (1991) Changes in microbial population numbers during the composting of pine bark. *Bioresources Technology* **39**: 85-92.

Donald, D.G.M. (1982) The use of paraquat to stimulate resin production in pine trees. *Wood, Southern Africa* **7**(8): 37.

Donald, D.G.M. (1983) The application of fertilizer to pole stage crops. In: Forestry *Quo Vadis*. Pietermaritzburg, South Africa, June, 1983. Faculty of Forestry, University of Stellenbosch, South Africa, 59-71.

Durand, P.Y. (1983) Variations in wood properties and pulping characteristics of some tropical pines grown in plantation. *Silvicultura* **32**: 816-820.

Dvorak, W.S. and Donahue, J.K. (1992) CAMCORE cooperative research review 1980-1992. Department of Forestry, North Carolina State University, Raleigh, USA, 93 pp.

Dyson, W.G. (1971) Wood properties of young pine trees grown at Muguga arboretum. East African Agriculture and Forest Research Organization, Nairobi, Kenya, Technical Note No. 28, 5 pp.

Earl, D.E. (1974) A report on charcoal. Andre Mayer Fellowship, FAO, Rome, Italy, 97 pp.

Eccles, D.B., Alcock, J. and Smith, W.J. (1975) Incidence and effect of resin pockets in *Pinus patula*. In: Proceedings of 17th Forest Products Research Conference. CSIRO, Melbourne, Australia.

Eckbo, N.B. (1926) Report on the physical and mechanical properties of *Pinus patula*. South *Africa Journal of Science* **23**: 467-471.

Eguiluz Piedra, T. (1988) Distribucion natural de los pinos en Mexico. Centro de Genetica Forestal, Chapingo, Mexico, Nota Tecnica No. 1, 6 pp.

Eklund, R., Wallgren, H. and Virkola, N. (1974) Pulping and bleaching tests of Malawian pines. Report for FAO. Jaakko Poyry & Co., Helsinki, Finland.

Emerton, H.W. and Goldsmith, V. (1956) The structure of the outer secondary wall of pine tracheids from kraft pulps. *Holzforschung* **10**: 108-115.

Endo, M. and Velez M., G. (1992a) Results of a *Pinus patula* pruning trial. Smurfit Carton de Colombia, Cali, Colombia, Research Report No. 134, 8 pp.

Endo, M. and Velez M., G. (1992b) Results of a pruning trial with *Pinus patula* in Colombia. *IPEF International* **2**: 45-49.

Escobar S., R.A. and Uribe B., G. (1970) Silvicultura y posibles usos del *Pinus patula* en Antioquia. Unpublished thesis, Universidad Nacional, Facultad de Ciencias Agricolas, Medellin, Colombia, 121 pp.

Evans, J. (1974) Some aspects of the growth of *Pinus patula* in Swaziland. *Commonwealth Forestry Review* **53**: 57-62.

Evans, J. (1978) Some growth effects of hail damage and drought in *P. patula* plantations. *South African Forestry Journal* **105**: 8-12.

Evans, M.I. (1984) Firewood versus alternatives: Domestic fuel in Mexico. Oxford Forestry Institute, University of Oxford, UK, Occasional Paper No. 23, 70 pp.

FAO. (1973) An annotated bibliography of *Pinus patula*. FAO, Rome, Italy, 88 pp.

FAO. (1980a) Pulping and paper-making properties of fast-growing plantation wood species. FAO, Rome, Italy, Forestry Paper No. 19/1, 465 pp.

FAO. (1980b) Pulping and paper-making properties of fast-growing plantation wood species. FAO, Rome, Italy, Forestry Paper No. 19/2, 390 pp.

FAO. (1986) Wood preservation manual. FAO, Rome, Italy, Forestry Paper No. 76, 152 pp.

Ferreira, M., Amaral, A.C., Bertolani, F. and Nicolielo, N. (1978) Rendimento em peso seco de madeira de plantacoes de pinheiros. *IPEF* **17**: 78-89.

Fougerousse, M., Gueneau, P. Deon, G. and Thiel, J. (1971) Tests on sap displacement impregnation of *Eucalyptus robusta* and *Pinus patula* poles in Madagascar. *Material-und-Organismen* **6**: 101-139.

Frank, D. and Low, C. (1966) Painting of South African (pine) and Oregon pine (Douglas-fir) with reference to various pre-treatments and South African climatic conditions. *Architect and Builder* (Cape Town, South Africa) **16**: 11-12.

Fronius, K. (1984) Manufacture of laminated wood from fast growing pines in South Africa. *Holz-Zentralblatt* **110**(5): 40-41.

Fry, G. (1957) Density of the wood of *Pinus patula* grown in Kenya. Annual Report, Imperial Forestry Institute, University of Oxford, UK, 1955/56, 18 pp.

Fry, G. and Chalk, L. (1957) Variation in the density of the wood of *Pinus patula* grown in Kenya. *Forestry* **30**: 29-45.

Furlong, J.R. and Hill, E.L. (1944) Paper-making materials of the British Empire. *Bulletin of the Imperial Institute* **42**: 232-250.

Galloway, G. (1987) Criterios y estrategias para el manejo de plantaciones forestales en la sierra ecuatoriana. Direccion Nacional Forestal, Quito, Ecuador, 145 pp.

Garrido, M.A.O., Ribas, C., Assini, J.L. and Gurgel Garrido, L.M.A. (1983) Pesquisa sobre resinagem no Instituto Florestal. *Silvicultura* **33**: 48-53.

Geary, T.F. (1970) Objectives for the improvement of the quality of pines grown in central Africa. *Commonwealth Forestry Review* **49**: 52-63.

Gent, P.K. van (1958) Analysis of treated timber for preservative retention: a comparison of analytical and calculated results obtained from *Pinus patula* treated respectively with an oil and water soluble preservative. *South African Industrial Chemist* **12**(4): 71-74.

Gerischer, G.F.R. and Kromhout, C.P. (1964) Notes on breast height spirality in dominant trees of *Pinus patula*, *Pinus taeda* and *Pinus elliottii* with special reference to tree breeding. *Forestry in South Africa* **5**: 81-97.

Gerischer, C.F.R. and Villiers, A.M. de (1963) The effect of heavy pruning on timber properties. *Forestry in South Africa* **3**: 15-41.

Gerischer, G., Wyk, W.J. van, and Malan, F.S. (1976) Reduction in strength as a result of compression failure in wind damaged *Pinus patula* timber. *South African Forestry Journal* **96**: 19-22.

Ghosh, R.C. and Guhathakurta, P. (1973) *Pinus patula* Schl. and Cham. Its problems and prospects in West Bengal. *Indian Forester* **99**: 337-348.

Gonin, C.R. (1973) Physical and chemical properties of importance in pine pulpwood breeding. In: Proceedings of IUFRO Division V, University of Stellenbosch, South Africa, October, 1973. Faculty of Forestry, Stellenbosch, South Africa, 326-343.

Goodwin-Bailey, C.I. (1989) Relationship between the anatomical and end use properties of the wood of selected tropical pines. Internal Document, Oxford Forestry Institute, University of Oxford, UK.

Gorter, G.J.M.R. (1978) Lignicolous marine fungi on submerged wood from the Atlantic coast of South Africa. *South African Forestry Journal* **104**: 11-14.

Griffith, A.L. (1957) Use of wood preservatives on transplant boxes. East African Agriculture and Forest Research Organization, Nairobi, Kenya, 59 pp.

Grut, M. (1965) *Forestry and forest industry in South Africa.* A.A. Balkema, Cape Town, South Africa, 115 pp.

Gueneau, P. (1970) Characteristics and uses of pines in Madagascar (*Pinus patula* and *Pinus khasya*). *Bois et Forêts des Tropiques* **133**: 39-51.

Gueneau, P. (1971) Bois de Madagascar possibilites d'emplois. Centre Technique Forestier Tropical, Tananarive, Madagascar, 75 pp.

Gueneau, P. and Fougerousse, M. (1969) Etude sur l'utilisation a Madagascar de bois locaux comme supports de lignes. Nota Tecnique, Centre Technique Forestier Tropical, Tananarive, Madagascar, No. 8, 75 pp.

Guha, S.R.D., Sharma, Y.K. and Karira, B.G. (1976) Pulping of *Pinus patula. Ippta* **13**(1): 17.

Gurgel Garrido, L.M.A. and Garrido, M.A.O. (1988) Selecao em *Pinus* tropicais para producao de resina. *Silvicultura* **20/22**: 41-46.

Guth, E. (1970) Variacion de caracters fisicos y quimicos en especies subtropicales de *Pinus* en localidades del norte Argentina. I. Densidade morfologia de las traqueidas. IDIA Suplemento Forestal No. 6: 33.

Harris, J.M. (1989) *Spiral grain and wave phenomena in wood formation.* Springer Verlag, Berlin, Germany, 215 pp.

Hinds, H.V. (1968) Annual Report. Forest Research Institute, Rotorua, New Zealand, 1967, 73 pp.

Hock, R. and Mariaux, A. (1984) Vitesse de croissance et retrait du bois: relation entre la largeur des cernes d'accroissement et le retrait au sechage dans quelques arbres tropicaux. *Bois et Forêts des Tropiques* **203**: 79-90.

Hoheisel, H. and Lopez, O. (1973) Secado al aire libre y artificial de postes para cercas de cipres y pino patula. Universidad Nacional, Medellin, Colombia, Revista Facultad Nacional de Agronomia XXVIII: 42-51.

Howland, P. (1971) The air seasoning of *Pinus patula* lumber in Malawi. Malawi Forest Research Institute, Zomba, Malawi, Research Record No. 51, 18 pp.

Howland, P. and Matabwa, C.J. (1971) Equilibrium moisture content of seasoned wood in Malawi. Part II. Specific E.M.C. values for important species. Malawi Forest Research Institute, Zomba, Malawi, Research Record No. 52, 22 pp.

Howland, P. and Paterson, D.N. (1969) A preliminary study in resawing seasoned *Pinus patula* construction grade lumber. Malawi Forest Research Institute, Zomba, Malawi, Research Record No. 31, 5 pp.

Howland, P. and Paterson, D.N. (1971) Variation in morphology, grade out-turn and physical properties in seven pine and one cypress species grown on an average Malawi site. Malawi Forest Research Institute, Zomba, Malawi, Research Record No. 39, 5 pp.

Huy, V.R. (1985) Measurement of moisture content in resinous wood. In: Proceedings, Symposium on forest products research international-acheivements and the future. Pretoria, South Africa, April, 1985. Council for Scientific and Industrial Research, Pretoria, South Africa, Paper No. 16-20, 10 pp.

IPEF. (1978) Resina de *Pinus* implantados no Brasil. Departamento de Silvicultura, Universidade de Sao Paulo, Brazil, Circular Tecnica No. 34, 17 pp.

Ishengoma, R.C. and Klem, G.S. (1979) Yield, quality, cost and market acceptability of charcoal from softwood slabs. Division of Forestry, Faculty of Agriculture, Forestry and Veterinary Science, University of Dar es Salaam, Tanzania, Record No. 4, 16 pp.

Ishengoma, R.C., Mrema, F.A.J. and Ringo, W.N. (1990) Basic density and tracheid length of normal and compression wood from plantation grown *Pinus patula*. Faculty of Forestry, Sokoine University of Agriculture, Morogoro, Tanzania, Record No. 44, 22 pp.

Jansen, A., Pizzi, A. and Conradie, W.E. (1985) The penetration characteristics of CCA preservatives in wood radial/tangential, process and species effects. *Holz-als-und-Werkstoff* **43**: 181-186.

Kalish, J. (1977) South Africa's forest: fast growing exotics, large plantations offer strong forest potential. *World Wood* **18**: 12-17.

Karani, P.K. (1978) Pruning and thinning in a *Pinus patula* stand at Lendu plantation, Uganda. *Commonwealth Forestry Review* **57**: 269-278.

Keinert, S., Jr. (1988a) Structural composition boards from pines and eucalyptus. In: Proceedings of Bilateral Symposium, Brazil-Finland on Forestry Activities. Curitiba, Parana, Brazil, October, 1988. (Eds. Carneiro, J.G. de A. *et al.*). EMBRAPA, Curitiba, Brazil, 294-305.

Keinert, S. Jr. (1988b) Chapas de particulas estruturais a partir de *Pinus* e *Eucalyptus* spp. In: Proceedings of Bilateral Symposium, Brazil-Finland on Forestry Activities. Curitiba, Parana, Brazil, October, 1988. (Eds. Carneiro, J.G. de A. *et al.*). EMBRAPA, Curitiba, Brazil, 315-326.

Kibuku, M.D.N., Karanja, G., Kamiri, J.M. and Kihura, L. (1972) Wood properties studies. Annual Report, East African Agriculture and Forest Research Organization, Nairobi, Kenya, 1971, 235 pp.

Klashorst, G.H. van der (1988) Low molecular mass lignin fragments present in industrial kraft pine spent liquor. *Holzforschung* **42**: 65-66.

Klashorst, G.H. van der, Cameron, F.A. and Pizzi, A. (1985) Lignin-based cold setting wood adhesives-structural fingerjoints and glulam. *Holz-als-Roh-und-Werkstoff* **43**: 477-481.

Knuffel, W.E. (1985) The effect of CCA preservative treatment on the compressive strength of South African pine structural timber. *Holzforschung-und-Holzverwertung* **37**(5): 96-99.

Knuffel, W.E. (1988a) Acoustic emission as strength predictor in structural timber. *Holzforschung* **42**: 195-198.

Knuffel, W.E. (1988b) The piezoelectric effect in structural timber. Part II. The influence of natural defects. *Holzforschung* **42**: 247-252.

Knuffel, W., Pizzi, A. and Knuffel, W.E. (1986) The piezoelectric effect in structural timber. *Holzforschung* **40**: 157-162.

Kotze, J.J. and Eckbo, N.B. (1926) *Pinus patula* Schl. et Cham. Its introduction into and growth in South Africa with a report on the physical and mechanical properties of its timber. *South Africa Journal of Science* **XXIII**: 455-456.

Krogh, P.M.D. (1961) A marine exposure test of chemically impregnated poles and untreated controls in South African harbours. *Forestry in South Africa* **1**: 51-72.

Kromhout, C.P. (1963) Aantekeninge oor trageidelengtes in *Pinus patula*, *Pinus taeda* en *Pinus elliottii*. *Forestry in South Africa* **2**: 93-98.

Kromhout, C.P. (1966) A note on spirality measurements on stem samples for tree breeding purposes. *Forestry in South Africa* **6**: 79-86.

Kromhout, C.P. and Toon, R.E. (1978) Variation of wood properties of some tropical species grown in plantations in Southern Africa. In: Progress and problems of genetic improvement of tropical forest trees. Brisbane, Australia, April, 1977. (Eds. Nikles, D.G., Burley, J. and Barnes, R.D.). Commonwealth Forestry Institute, Oxford, UK, 8-45.

Kromhout, C.P. and Bosman, D.L. (1981) The influence of short rotation forestry on wood production for sawnwood and veneer. *South African Forestry Journal* **120**: 13-18.

Kromhout, N. (1978) Potential of fast grown tropical pines for uses other than pulp and paper in Southern Africa. In: Progress and problems of genetic improvement of tropical forest trees. Brisbane, Australia, April, 1977. (Eds. Nikles, D.G., Burley, J. and Barnes, R.D.). Commonwealth Forestry Institute, Oxford, UK, 162-166.

Kronka, F.J.N. (1974) Tabelas de volume para algunas especies de genero pinus. Boletin Tecnico, Instituto Florestal, Sao Paulo, Brazil, No. 12, 8 pp.

Ladrach, W.E. (1975) Preliminary analysis of the wood characteristics of six conifer species in Colombia. Smurfit Carton de Colombia, Cali, Colombia, Research Report No. 13, 14 pp.

Ladrach, W.E. (1978) Tables of volume, green weight, and dry weight of *Pinus patula*. Smurfit Carton de Colombia, Cali, Colombia, Research Report No. 38, 4 pp.

Ladrach, W.E. (1983) Ten year growth of the Chupillauta arboretum. Smurfit Carton de Colombia, Cali, Colombia, Research Report No. 82, 8 pp.

Ladrach, W.E. (1984) Wood quality of *Pinus patula* Schl. et Cham. Smurfit Carton de Colombia, Cali, Colombia, Research Report No. 92, 17 pp.

Ladrach, W.E. (1985) Woodyard conversion factors for conifers. Smurfit Carton de Colombia, Cali, Colombia, Research Report No. 104, 3 pp.

Ladrach, W.E. (1986a) Comparisons between provenances of seven conifers in the Andean region after eight years. Smurfit Carton de Colombia, Cali, Colombia, Research Report No. 105, 8 pp.

Ladrach, W.E. (1986b) Control of wood properties in plantations with exotic species. Smurfit Carton de Colombia, Cali, Colombia, Research Report No. 106, 12 pp.

Ladrach, W.E. (1987) Growth and heritability estimates for a seven-year-old open-pollinated patula pine progeny trial. Smurfit Carton de Colombia, Cali, Colombia, Research Report No. 115, 16 pp.

Ladrach, W.E. and Mazuera, H. (1978) Growth and development of the Chupillauta arboretum at 7 years, and the Mexican pines in San Jose at 6.3 years. Smurfit Carton de Colombia, Cali, Colombia, Research Report No. 34, 4 pp.

Ladrach, W.E. and Lambeth, C.C. 1991. Growth and heritability estimates for a seven-year-old open-pollinated *Pinus patula* progeny test in Colombia. *Silvae Genetica* **40**: 169-173.

Lambeth, C., Osorio, G. and Osorio, L.F. (1989) Blue stain incidence in commercial plantation species in Colombia: effects of storage time and debarking. Smurfit Carton de Colombia, Cali, Colombia, Research Report No. 122, 8 pp.

Lamprecht, H. (1989) Silviculture in the tropics. Deutsche Gesellschaft fur Technische Zusammenarbeit (GTZ) GmbH, Eschborn, Germany, 210-212.

Lastra R., J.A. (1986) Compilacion de las propiedades fisico-mecanicas y usos posibles de 178 maderas de Colombia. Asociacion Colombiana de Ingeneiros Forestales, Bogota, Colombia, Libro Tecnico No. 1, 74 pp.

Lema, C.N., Kitali, M.M. and Klem, G.S. (1978) Basic density and its variation within and between trees of pine (*Pinus patula*) and cypress (*Cupressus lusitanica*) in the Meru Forest Project. Division of Forestry, Faculty of Agriculture, Forestry and Veterinary Science, University of Dar es Salaam, Tanzania, Record No. 3, 11 pp.

Lewis, N.B. (1964) Observations on thinning and pruning in South Africa. *Commonwealth Forestry Review* **43**: 116-133.

Liese, W. (1960) Elektronenmikroskopie des Holzes. Mitt. StForstverw. *Bayers* **31**: 115-130.

Liese, W. and Cote, W.A. Jr. (1960) Electron microscopy of wood: results of the first ten years of research. In: Proceedings of the Fifth World Forestry Congress, Seattle. Department of Forestry, University of Washington, Seattle, USA, 1288-1298.

Lipangile, T.N. (1990) *Bamboo and woodstave technology*. Printpak, Dar es Salaam, Tanzania, 175 pp.

Lockhart, L.A. (1990) Chemotaxonomic relationships within the Central American closed-cone pines. *Silvae Genetica* **39**: 173-184.

Logie, J.P.W. (1966) Timber supplies in Kenya. In: Proceedings Second East African timber symposium. (Ed. Campbell, P.A.). Department of Civil Engineering, University College, Nairobi, Kenya, 4 pp.

Loock, E.E.M. (1977) The pines of Mexico and British Honduras. Department of Forestry, Pretoria, South Africa, Bulletin No. 35, 246-249.

Loseby, P.J.A. (1935) An evaluation of South African grown *Pinus patula* by the sulphate (kraft) process. *Bulletin of the Imperial Institute* **XXXIII**: 162-171.

Loseby, P.J.A. (1939) Pulp and paper making as a South African industry. Journal of the *South African Forestry Association* **18**: 55-71.

Lubomir, K. (1969) The assessment of main wood properties for tree breeding of *Pinus patula* in Tanzania. *Silvaecultura Tropica et Subtropica* **1**: 61-76.

Luckhoff, H.A. (1949) The effect of live pruning on the growth of *Pinus patula*, *P. caribaea* and *P. taeda* (in South Africa). *Journal of the South African Forestry Association* **18**: 25-55.

Luckhoff, H.A. (1956) High pruning in *Pinus patula*, its feasibility, effect on growth and economics. *Journal of the South African Forestry Association* **27**: 55-71.

Malan, F.S. and Hoon, M. (1991) The wood properties of three *Pinus tecunumanii* provenances from Tweefontein State Forest. Council for Scientific and Industrial Research, Division of Forest Science and Technology, Pretoria, South Africa, Report No. FORI 146, 59 pp.

Malhotra, P.P., Tandon, V.N. and Kumar, P. (1985) Biomass production, its distribution and biological productivity in *Pinus patula* Schl. and Cham. plantations in Nilgris. *Indian Forester* **111**: 12-21.

Malimbwi, R.E. and Philip, M.S. (1989) A compatible taper/volume estimation system for *Pinus patula* at Sao Hill Forest Project, southern Tanzania. *Forest Ecology and Management* **27**: 109-115.

Marais, L.J. and Kotze, J.M. (1975) Mycorrhizal associates of *Pinus patula* in South Africa. *South African Forestry Journal* **92**: 13-16.

Marais, L.J. and Kotze, J.M. (1977) Notes on ectotrophic mycorrhizae of *Pinus patula* in South Africa. *South African Forestry Journal* **100**: 61-71.

Marshall, H.G.W. and Foot, D.L. (1969) Growth and silviculture of *Pinus patula* in Malawi. Malawi Forest Research Institute, Zomba, Malawi, Research Record No. 37, 58 pp.

Masuka, A.J. and Kariwo, P. (1992) Sapstain and mold in pine logs in Zimbabwe. *Commonwealth Forestry Review* **71**: 193-196.

Mejia M., L.C. and Escobar C., O. (1984) Ensayos de flexion estatica en postes de pino (*Pinus patula*) para instalaciones electricas y telefonicas. Laboratorio de Productos Forestales, Universidad Nacional, Medellin, Colombia. Madera III: 34-40.

Merwe, J.J. van der (1973a) Strength and warp in kiln-dried S.A. pine timber as affected by the drying process, spiral grain and other factors. In: Proceedings of IUFRO Division V. Pretoria, South Africa. Council for Scientific and Industrial Research, Pretoria, South Africa, Vol. II: 1047-1055.

Merwe, J.J. van der (1973b) Strength and warp in kiln-dried S.A. pine timber as affected by the drying process, spiral grain and other factors. Council for Scientific and Industrial Research, Pretoria, South Africa, Special Report No. 56, 10 pp.

Mih, J.F., Kramer, J.D. and Cubillos, J. (1985) The bleaching of kraft pulps from Colombian hardwoods and plantation woods. In: Proceedings CPPA/TAPPI International Pulp Bleaching Conference, Quebec City. TAPPI, Atlanta, Georgia, USA, 17-25.

Mirov, N.T. (1957) Composition of turpentines of Mexican pines. *Unasylva* **8**: 167-173.

Mirov, N.T. (1961) Composition of gum turpentines of pines. Pacific Southwest Range and Experiment Station, Berkeley, California, USA, Technical Bulletin No. 1239, 158 pp.

Moorthy, V.L., Guha, S.R.D., Sharma, Y.K. and Mathur, G.M. (1977) Evaluation of softwoods viz., *Cupressus lusitanica*, *Pinus radiata* and *Pinus patula* for paper making. *Indian Forester* **103**: 336-348.

Moreschi, J.C., Tomaselli, I. and Richter, H.G. (1977) Contribuicao ao estudo da densidade basica de coniferas plantadas no sul do Brasil. *Revista Floresta* **8**: 26-28.

Morris, A. (1982a) A preliminary report on biomass studies on *Pinus patula* at the Usutu Forests. Usutu Pulp Company Limited, Swaziland, Forest Research Report No. 134, 12 pp.

Morris, A. (1982b) Aboveground biomass of very young *Pinus patula* trees. Usutu Pulp Company Limited, Swaziland, Forest Research Report No. 38, 7 pp.

Morris, A. (1985a) A comparison of the growth of *Pinus patula* & *Pinus elliottii* in the Usutu Forest. Usutu Pulp Company Limited, Swaziland, Forest Research Report No. 75, 12 pp.

Morris, A. (1985b) Biomass and nutrient content of an age series of *Pinus patula* stands in the Usutu Forest. Part I. Dry weather accretion. Usutu Pulp Company Limited, Swaziland, Forest Research Report No. 84, 14 pp.

Morris, A.R. (1993) Forest floor accumulation under *Pinus patula* in the Usutu Forest, Swaziland. *Commonwealth Forestry Review* **72**: 114-117.

Mortenson, E. and Paterson, D.N. (1968) Wood quality studies in 18 year old exotic softwood plantations. In: Proceedings Third East African Timber Symposium. Nairobi, Kenya. Department of Civil Engineering, University College, Nairobi, Kenya, 6 pp.

Murira, K.K. (1984) Natural durability tests of Tanzanian timbers (1955-1982). Tanzania Forestry Research Institute, Moshi, Tanzania, 15 pp.

Myburgh, H.H. and Mackenzie, A.A. (1966) The production of timber for pulpwood. *South African Forestry Journal* **58**: 21-29.

Ordonez, V., Barcenas, G. and Quiroz, A. (1989) Caracteristicas fisico-mecanicas de la madera de diez especies de San Pablo Macuilitanguis, Oaxaca. Madera y Su Uso 21, 30 pp.

Orman, H.R. (1952) Physical properties of *Pinus patula* from Whakarewarewa and Kaingora State Forests. Forest Research Institute, Wellington, New Zealand, Research Note No. 1(3), 24 pp.

Otto, K.P. and van Vuren W.F.J. (1976) The mechanical properties of timber with particular reference to those grown in the Republic of South Africa. Bulletin, Department of Forestry, Pretoria, South Africa, No. 48, 88 pp.

Palmer, E.R. (1985) The selection of seed trees with particular reference to pulping properties. *Appita* **38**: 182-184.

Palmer, E.R. (1987) Pulping characteristics of *Pinus* spp. grown in Zimbabwe. *Commonwealth Forestry Review* **66**: 375-376.

Palmer, E.R. and Tabb, C.B. (1968) Production of pulp and paper from coniferous species grown in the tropics. *Tropical Science* **10**: 79-99.

Palmer, E.R. and Gibbs, J.A. (1974) Pulping qualities of plantation grown *Pinus patula* and *Pinus elliottii* from Malawi. Tropical Products Institute, London, UK, Report No. L37, 36 pp.

Palmer, E.R., Gibbs, J.A. and Dutta, A.P. (1982a) Pulping trials of wood species grown in plantations in Kenya. Tropical Products Institute, London, UK, Report No. L61, 58 pp.

Palmer, E.R., Johnson, J.S., Ganguli, S., Gibbs, J.A. and Dutta, A.P. (1982b) Pulping trials on *Pinus patula* and *Pinus radiata* grown in plantations in Kenya. Tropical Products Institute, London, UK, Report No. L63, 56 pp.

Palmer, E.R., Ganguli, S. and Gibbs, J.A. (1984) Pulping properties of *Pinus caribaea, Pinus elliottii* and *Pinus patula* growing in Tanzania. Tropical Products Institute, London, UK, Report No. L66, 32 pp.

Palmer, E.R. and Ganguli, S. (1988) Pulping characteristics of *Pinus patula* grown in Zimbabwe. Overseas Development and Natural Resources Institute, London, UK, Bulletin No. 8, 32 pp.

Panda, R. and Panda, H. (1986) Studies on pine oleoresin. Part I: resin acid compositions. *Indian Forester* **112**: 157-162.

Pande, G.C. (1982) Tropical pines in India - An overview. *Indian Forester* **108**: 1-28.

Parrish, J.R. (1958) Particle board from wattle wood and wattle tannin. *Journal of the South African Forestry Association* **32**: 26-31.

Paterson, D.N. (1963) The strength of Kenya timber: their derivation and application. Kenya Forest Department, Nairobi, Kenya, Research Bulletin No. 23.

Paterson, D.N. (1965) The development and use of stress grading in East Africa. In: Proceedings First East African Timber Symposium, Nairobi. Department of Civil Engineering, University College, Nairobi, Kenya, 4 pp.

Paterson, D.N. (1966a) A quality assessment of the exotic softwoods of East Africa for sawn timber. *Commonwealth Forestry Review* **45**: 212-223.

Paterson, D.N. (1966b) Crude estimates of genetic gains from plus-trees selected in the East African tree breeding programme. East African Agriculture and Forestry Research Organization, Nairobi, Kenya, Technical Note No. 18, 14 pp.

Paterson, D.N. (1967) The grading of plus phenotypes, its significance in silviculture and volume yields in East Africa. East African Agriculture and Forestry Research Organization, Nairobi, Kenya, Technical Note No. 21, 17 pp.

Paterson, D.N. (1968a) Control of wood quality in the East African exotic softwood tree breeding programme. *East Africa Agricultural and Forestry Journal* **33**: 302-315.

Paterson, D.N. (1968b) Selection of breeding trees. Report, East African Agriculture and Forest Research Organization, 1967/1968, Nairobi, Kenya, 114-120.

Paterson, D.N. (1968c) Further studies in wood quality, wood quantity, wood value and rotations from core wood analysis. East African Agriculture and Forest Research Organization, Nairobi, Kenya, Technical Note No. 22, 10 pp.

Paterson, D.N. (1968d) Spiral grain in East African exotic softwood forest plantations. *East Africa Agricultural and Forestry Journal* **33**: 286-291.

Paterson, D.N. (1969a) Genetic gains predicted for seed to be produced from Malawian seed orchards. Malawi Forest Research Institute, Zomba, Malawi, Research Record No. 32.

Paterson, D.N. (1969b) Further studies in wood quality, wood quantity, wood value and rotations from wood quality analysis. *East African Agricultural and Forestry Journal* **34**: 33-44.

Paterson, D.N. (1970) The effect of logging losses and log volume tables on yield production and tree purchase values in Malawi. Malawi Forest Research Institute, Zomba, Malawi, Research Record No. 41, 4 pp.

Paterson, D.N. (1971a) The derivation and application of strength values in some Malawian timbers. Part 1. Small clears data. Malawi Forest Research Institute, Zomba, Malawi, Research Record No. 49, 10 pp.

Paterson, D.N. (1971b) Stress grading Malawi timbers. Malawi Forest Research Institute, Zomba, Malawi, Supplement to Research Record No. 54, 10 pp.

Paterson, D.N. and Campbell, P.A. (1970) Strength variations and correlations in East African exotic pines and their effect on engineering properties. *East African Agricultural and Forestry Journal* **35**: 7-19.

Paterson, D.N. and Howland, P. (1971) Shrinkage, distortion and density in some Malawian timbers. Malawi Forest Research Institute, Zomba, Malawi, Research Record No. 46, 22 pp.

Patino, V.F. and Kageyama, P.Y. (1991) *Pinus patula* Schiede and Deppe. Danida Forest Seed Center, Humlebaek, Denmark, Seed Leaflet No. 8a, 25 pp.

Paz Perez, O. de la and Olvera, C.,P. (1981) Anatomia de la madera de 16 especies de coniferas. Instituto Nacional de Investigaciones Forestales, Mexico City, Mexico, Boletin Technico No. 69, 111 pp.

Pendlebury, A.J., Coetzee, J., Sorfa, E. and Botha, A. (1991) A new technique to determine solvent penetration in wood. *Holzforschung* **45**: 205-208.

Perry, J.P. Jr. (1991) *The pines of Mexico and Central America.* Timber Press, Portland, Oregon, USA, 231 pp.

Petroff, G. (1968) A paper-pulp mill in Angola. *Bois et Forêts des Tropiques* **119**: 31-42.

Petroff, G., Doat, J. and Tissot, M. (1968) Caracteristiques papetieres de quelques essences tropicales de reboisement. Centre Technique Forestier Tropical, Nogent-sur-Marne, France, Publication No. 31, 193 pp.

Pinheiro, G. de S., Brasil, M.A.M., Veiga, R.A. de A. and Buzatto, O. (1986) Estimativa do peso de madeira seca em plantios de *Pinus*, atraves de parametros dendrometricos. Instituto Florestal de Sao Paulo, Boletin Tecnico No. 40: 135-151.

Pizzi, A. (1982) Pine tannin adhesives for particleboard. *Holz als Roh-und-Werkstoff* **40**: 293-301.

Pizzi, A. (1990) Mechanisms of wood waterproofing with CrO_3/varnish emulsions. *Holzforschung-und-Holzverwertung* **42**(3): 52-55.

Pizzi, A., Cameron, F.A., Goulding, T.M., Kes, E. and Westhuizen, P.K. van der (1983) "Honeymoon" fast-setting adhesives for timber laminating. *Holz-als-Roh-und-Werkstoff* **41**: 61-63.

Pizzi, A., Conradie, W.E. and Jansen, A. (1984) Sludge formation in timber treatment with CCA preservatives: origin and elimination. *Holzforschung-und-Holzverwertung* **36**(3): 54-59.

Pizzi, A. and Conradie, W.E. (1986) A chemical balance/microdistribution theory - new formulations for soft-rot control. *Material-und-Organismen* **21**: 31-46.

Pizzi, A., Vosloo, R., Cameron, F.A. and Orovan, E. (1986a) Self-nuetralizing acid-set PF wood adhesives. *Holz-als-Roh-und-Werkstoff* **44**: 229-234.

Pizzi, A., Conradie, W.E., Jansen, A. and Vosloo, R. (1986b) A series of low toxicity wood preservatives. *Holzforschung-und-Holzverwertung* **38**(6): 139-140.

Pizzi, A., Conradie, W.E. and Jansen, A. (1986c) Polyflavonoid tannins-a main cause of soft-rot failure in CCA-treated timber. *Wood Science and Technology* **20**: 71-81.

Plooy, A.B.J. du (1978) Whole tree utilization - the biomass and pulp quality of 15 year old *P. patula* grown in the Eastern Transvaal. National Timber Research Institute, Pretoria, South Africa, Special Report No. 165, 44 pp.

Plooy, A.B.J. du (1982a) Alkaline and semialkaline sulfite pulping of *Pinus patula*. National Timber Research Institute, Pretoria, South Africa, Special Report No. 235, 60 pp.

Plooy, A.B.J. du (1982b) Bleaching of *Pinus patula* alkaline sulfite pulps. National Timber Research Institute, Pretoria, South Africa, Special Report No. 279, 24 pp.

Plooy, A.B.J. du and Venter, J.S.M. (1981) The kraft and thermo-mechanical pulp quality of ten year old *P. patula* and *P. greggii*. National Timber Research Institute, Pretoria, South Africa, Report No. 205, 17 pp.

Plumptre, R.A. (1967) The utilization of conifer thinnings from small plantations in Uganda. In: Proceedings World symposium on man-made forests and their industrial importance. Canberra, Australia, April, 1967. FAO, Rome, Italy, Vol. IV: 2011-2014.

Plumptre, R.A. (1969) The shrinkage of some Uganda timbers. Uganda Forest Department, Entebbe, Uganda, Timber Leaflet No. 47, 3 pp.

Plumptre, R.A. (1972) Comparison of the anatomical and mechanical properties of the wood of *Pinus patula* grown in Uganda. Unpublished MSc thesis, University of Oxford, UK.

Plumptre, R.A. (1976) Some techniques used in the study of wood density. Internal document, Commonwealth Forestry Institute, University of Oxford, UK, 11 pp.

Plumptre, R.A. (1978) Some wood properties of *Pinus patula* from Uganda and techniques developed in studying them. Oxford Forestry Institute, University of Oxford, UK, Occasional Paper No. 4, 55 pp.

Plumptre, R.A. (1979) Pruning of fast growing pines for wood uniformity: can you have your cake and eat it? *Commonwealth Forestry Review* **58**: 181-189.

Plumptre, R.A. and Kasirye, B. (1969) The resistance of some Uganda timbers to vacuum-pressure impregnation with copper-chrome-arsenate wood preservatives. Forest Department, Ministry of Agriculture and Forestry, Kampala, Uganda, Bulletin No. 10, 19 pp.

Plumptre, R.A. and Austin, S. (1978) The influence of pruning on the wood density and rate of growth of *Pinus patula*. In: Proceedings of IUFRO Division V, Conference on Wood Quality and Utilisation of Tropical Species, College, Laguna, Philippines, October, 1978. Forest Products Research and Industries Development Commission, College, Laguna, Philippines.

Poynton, R.J. (1957) *Notes on exotic forest trees in South Africa.* Government Printer, Pretoria, South Africa, 135 pp.

Poynton, R.J. (1979) *Tree planting in southern Africa Volume 1. The pines.* Department of Forestry, Pretoria, South Africa, 576 pp.

Psotta, K. (1979) Composition of bark. (2). Bark of *Pinus patula.* Timber Research Institute, Pretoria, South Africa, CSIR Report No. 29, 14 pp.

Quinones, J.O. (1974) Caracteristicas fisicas y mecanicas de la madera de 5 especies mexicanas. Instituto Nacional de Investigacion Forestal, Mexico City, Mexico, Boletin Tecnico No. 42, 21 pp.

Reardon, G.F. and Boughton, G.N. (1984) Withdrawal resistance of grooved nails in seasoned pine. In: Proceedings of the Pacific Timber Engineering Conference. Auckland, New Zealand, May, 1984. (Ed. Hutchison, J.D.). Institution of Professional Engineers, Wellington, New Zealand, Vol. III: 907-914.

Record, S.J. and Hess, R.W. (1974) *Timbers of the New World*. Charles Lathrop Pack Foundation, New Haven, USA, 640 pp.

Reimao, D. de Sousa Castro. (1974) Ensaios de campo de produtos preservadores de madeiras. 1. Material e metodos. Instituto de Investigacao Agronomica de Angola, Nova Lisboa, Angola, 13 pp.

Reimao, D. de Sousa Castro. (1975) Ensaios com postes de madeira preservados. I. Material e metodos. Instituto de Investigacao Agronomica de Angola. Nova Lisboa, Angola, 16 pp.

Rensburg, B.W.J. van, Burdzik, W.M.G., Ebersohn, W. and Cillie, C. (1987) The effect of timber density and type of adhesive on the strength of finger-joints in S.A. pine and *Eucalyptus grandis*. *South African Forestry Journal* **140**: 39-43.

Ringo, W.N. (1983) Basic density and tracheid length in juvenile and mature wood in *Pinus patula* from southern Tanzania. Unpublished thesis, Sokoine University of Agriculture, Morogoro, Tanzania.

Ringo, W.N. and Klem, G.S. (1980) Basic density and heartwood content in the wood of *Pinus patula* from Sao Hill. Division of Forestry, Faculty of Agriculture, Forestry and Veterinary Science, University of Dar es Salaam, Tanzania, Record No. 14, 17 pp.

Ringo, W.N. and Klem, G.S. (1986) Effect of sampling direction on wood density and tracheid length in stems of *Pinus patula*. *Indian Journal of Forestry* **9**: 157-160.

Ringo, W.N. and Klem, G.S. (1989) Effect of ring width on density and tracheid length in the wood of *Pinus patula*. *Indian Journal of Forestry* **12**: 179-182.

Robertson, P.E. (1991) The pulping characteristics of *P. tecunumanii*, *P. patula* and *P. taeda*. Division of Forest Science and Technology, Pretoria, South Africa, Report No. FORI 183, 17 pp.

Rogers, G.M. and Baecker, A.A.W. (1987) Theories on the degradation in wood associated with glycocalyx producing bacteria. *Journal of the Institute of Wood Science* **11**: 78-84.

Rogers, G.M. and Baecker, A.A.W. (1991) *Clostridium xylanolyticum* sp. nov., an anaerobic xylanolytic bacterium from decayed *Pinus patula* wood chips. *International Journal of Systematic Bacteriology* **41**: 140-143.

Saenz Romero, C. (1991) Personal communication.

Sanchez Mejorada, N. and Huguet, L. (1959) Las coniferas Mexicanas. *Unasylva* **13**: 24-35.

Schnippenkoetter, W.H., Abraham, L.D. and Baecker, A.A.W. (1988) Analysis of relative performances of DNBP and CCA wood preservatives in accelerated decay tests. *Material-und-Organismen* **23**: 301-319.

Schonau, A.P.G., Garbutt, D.C.F. and Boden, D.I. (1981) Variations in some physical and chemical properties of pulpwood grown at high altitudes in the Natal midlands. Report for 1980-1981, Wattle Research Institute, University of Natal, Pietermaritzburg, South Africa, 95-103.

Schutz, C.J. (1989) Site relationships for *Pinus patula* in the Eastern Transvaal escarpment area. Unpublished PhD thesis, University of Natal, Pietermaritzburg, South Africa, 334 pp.

Schwegmann, L.M (1956) The physical properties of fast- and slow-grown *Pinus patula* and *Pinus taeda* as grown in South Africa. Forest Research Institute, Pretoria, South Africa, Unpublished Report No. FP 210J/1.

Scott, M.H. (1935) Weights of South African grown timbers. Deptartment of Agriculture and Forestry, Pretoria, South Africa, Bulletin No. 145.

Scott, M.H. (1945) Timber seasoning in South Africa. Department of Agriculture and Forestry, Pretoria, South Africa, Bulletin No. 254, 40 pp.

Scott, M.H. (1946) The use of chemically treated wooden poles for telephone and power transmission lines in South Africa. *Journal of the South African Forestry Association* **13**: 21-34.

Scott, M.H. (1948) Timber seasoning in South Africa. Department of Agriculture and Forestry, Pretoria, South Africa, Bulletin No. 32, 41 pp.

Scott, M.H. (1949) Weight of timbers used in South Africa. *Journal of the South African Forestry Association* **17**: 73-112.

Scott, M.H. (1951) An unusually severe test for locally produced wooden shingles. *Journal of the South African Forestry Association* **20**: 78-80.

Scott, M.H. (1953) Notes on South African timbers. Department of Forestry, Pretoria, South Africa, Bulletin No. 36, 94 pp.

Scott, M.H. and Stephens, R.P. (1947) The quality of mature *P. patula* and *P. insignis* timber grown in South Africa. *Journal of the South African Forestry Association* **15**: 46-68.

Sekhar, A.C., Shukla, N.K. and Gandhi, B.L. (1974) A note on the strength properties of some exotic species. *Van-Vigyan* **12**(1/4): 1-7.

Sharma, S.C. and Srivastava, V.K. (1984) Biomass production in an age series of *Pinus patula* plantation in Tamil Nadu. *Indian Forester* **110**: 915-930.

Sharma, Y.K. (1983) Thermo-mechanical pulp for newsprint manufacture from tropical pines. *Ippta* **20**(1): 33-36.

Sharma, Y.K., Mathur, G.M., Bahadur, O. and Dhoundiyal, S.N. (1984) Newsprint grade pulps from *Pinus patula*. *Indian Forester* **110**: 673-681.

Sharma, Y.K., Bhandari, K.S. and Srivastava, A. (1987) Assessment of tropical pines for pulping and paper making characteristics. *Indian Forester* **113**: 127-139.

Sherry, S.P. (1961) Live pruning of *Pinus patula* and *P. elliottii* in South Africa. *Journal of the South African Forestry Association* **36**: 18-22.

Sherry, S.P. (1967) Is high pruning of *Pinus patula* economically justifiable? *Forestry in South Africa* **8**: 87-94.

Shukla, N.K. and Sangal, S.K. (1986) Preliminary studies on strength properties of some exotic timbers. *Indian Forester* **112**: 459-465.

Siemon, G.R. (1979) Bending strength and specific gravity of four exotic pines grown in south east Queensland. Department of Forestry, Queensland, Australia, Research Note No. 30, 5 pp.

Sijde, H.A., van der and Denison, N.P. (1967) Tree breeding in South Africa for the production of improved pine sawtimber. *Forestry in South Africa* **8**: 9-29.

Silva, M. Lopes de (1965) Possibilidade e interesse da introducao de resinosas exoticas em Angola. Alguns elementos para a sua cultura e exploracao. VI Jornadas Silvo-Agronomicas, Nova Lisboa, Angola, 11 pp.

Singh, B. (1982) Nutrient content of standing crop and biological cycling in *Pinus patula* ecosystem. *Forest Ecology and Management* **45**: 317-332.

Singh, B. (1984) Conservation and fixation of solar energy in *Pinus patula* plantations of Darjeeling Himalaya. *Biomass* **5**: 43-54.

Singh, M.M., Pant, R. and Sharma, Y.K. (1976) Comparative kraft pulping of pine and eucalyptus - changes in pulp properties throughout cooking cycle. *Ippta* **13**(2): 120.

Singh, R.P. (1972) *Pinus patula*: a perspective choice for pulpwood plantations. *Ippta* **9**(3): 160-166.

Skolmen, R.G. (1963) Wood density and growth of some conifers introduced into Hawaii. United States Forest Service, Pacific Southwest Forest and Range Experiment Station, Berkeley, California, USA, Research Paper No. PSW-12, 20 pp.

Smith, E.J. (1991) Groundwood and unbleached kraft pulp characteristics of 16/17 year old *P. kesiya* and *P. tecunumanii*. Sappi Management Services, Johannesburg, South Africa, Report No. R&D 91/045, 9 pp.

Solano C., O.E. (1987) Identificacion y control de los hongos causantes de la mancha azul en madera de pino patula en Antioquia. Laboratorio de Productos Forestales, Universidad Nacional, Medellin, Colombia. Madera VI: 17-29.

Sotelo, R.D., Echenique-Manrique, R. and Sanchez Velasco, J. (1978) Caracteristicas mecanicas de tres especies de pino del Cofre de Perote, Veracruz. *Biotica* **3**(1): 37-55.

Squillace, A.E. and Perry, J.P. (1992) Classification of *Pinus patula, P. tecunumanii, P. oocarpa, P. caribaea* var. *hondurensis* and related taxonomic entities. United States Forest Service, Southeastern Forest Experiment Station, Asheville, North Carolina, USA, Research Paper No. SE-285, 23 pp.

Standley, P.C. (1926) Trees and shrubs of Mexico. Contributions from the United States National Herbarium, Washington, DC, USA, Volume 23, 1721 pp.

Steinmann, D.E. and Vermaas, H.F. (1980) The determination and use of the volumetric change per unit mass moisture change, for some South African grown pine species. *South African Forestry Journal* **113**: 48-49.

Stohr, H.P. (1977) The effect of conventional seasoning methods on the twisting behaviour of young *Pinus patula* timber. *South African Forestry Journal* **101**: 31-38.

Stohr, H.P. (1980) Initial moisture content and density and drying rate of three pine species growing in the Natal midlands. Part I. Moisture content and density of standing trees. *South African Forestry Journal* **114**: 49-57.

Streets, R.J. (1962) *Exotic forest trees in the British Commonwealth.* Clarendon Press, Oxford, UK, 765 pp.

Stromberg, J and Miettinen, J.K. (1969) Comparison of wood/plastic composites (WPC) made of tropical pine (*Pinus patula*) and Scotch pine (*Pinus sylvestris*). *Paperi ja Puu* **51**: 785-790.

Tack, C.H. (1969) Uganda timbers. Ministry of Agriculture and Forestry, Forest Department, Entebbe, Uganda, 138 pp.

Tapia, C. (1986) The naval stores in Mexico. *Naval Stores Review* **96**(6): 11-14.

Thapa, H.B. (1987) Early thinning and pruning yields from *Pinus patula. Banko Janakari* **1**(3): 17-20.

Thornton, C.B. (1988) Neutral sulphite-anthraquinone pulping of Zimbabwean pine and eucalyptus. In: Tropical Wood Pulp Symposium, Singapore, June, 1988. Benn Publications Ltd., Tonbridge, Kent, UK, 194-204.

Tischler, K., Henriques, R., Schuster, H. and Kes, E.W.G. (1979a) Twist reduction of *Pinus patula* Schlecht. et Cham. lumber by mechanical constraint during kiln drying. Agriculture Research Organization, Division of Forestry, Israel, Leaflet No. 67, 11 pp.

Tischler, K., Kes, E.W.G., Henriques, R.M. and Schuster, H. (1979b) Twist reduction by mechanical restraint during kiln drying. National Timber Research Institute, Pretoria, South Africa, Special Report No. 169, 17 pp.

Tissot, M. (1968) The papermaking characteristics of some pine introduced into Africa and Madagascar. *Bois et Forêts des Tropiques* **118**: 41-55.

Tobon H., P. (1987) El peso especifico del *Pinus patula* por medio de muestras de incremento. Laboratorio de Productos Forestales, Universidad Nacional, Medellin, Colombia. Madera VI: 34-46.

Turnbull, J.M. (1937) Variations in strengths of pine timbers. *South Africa Journal of Science* **XXXIII**.

Turnbull, J.M. (1938) The influence of age on summerwood ratio in pine timber. *Journal of the South African Forestry Association* **1**: 53-59.

Turnbull, J.M. (1940) Fibril behaviour as disclosed by shrinkage observations. *Journal of the South African Forestry Association* **5**: 62-72.

Turnbull, J.M. (1941) The relationship between modulus of rupture and weight in South African grown pine timber. *Journal of the South African Forestry Association* **7**: 67-77.

Turnbull, J.M. (1947a) Some factors affecting wood density in pine stems. In: Fifth British Empire Forestry Conference, London, UK, 22-43.

Turnbull, J.M. (1947b) Some factors affecting wood density in pine stems. *Journal of the South African Forestry Association* **16**: 22-43.

Turnbull, J.M. and Plessis, C.P. du (1946) Some sidelights on the rate of growth bogey. *Journal of the South African Forestry Association* **14**: 29-36.

Turnbull, J.M. and Krogh, P.M.D. (1939) An improved pole testing machine. Journal of the *South African Forestry Associaiton* **3**: 103-107.

Uprichard, J.M. (1970) Pulps from New Zealand grown *P. patula* and *P. taeda*. *Appita* **24**: 52-59.

Uprichard, J.M and Gray, J.T. (1973) Papermaking properties of kraft pulps from New Zealand grown softwoods. *Appita* **27**: 185-191.

Vega, L. (1965) Observaciones silviculturales sobre *Pinus patula* en Cundinimarca, Colombia. *Turrialba* **15**: 325-335.

Vela Galvez, L. (1980) Contribucion a la ecologia de *Pinus patula*. Instituto Nacional de Investigaciones Forestales, Mexico City, Mexico, Publicacion Especial No. 19, 109 pp.

Vela Galvez, L. (1976) *Pinus patula*, una importante especie mexicana de pino. *Ciencia Forestal* **1**(1): 12-20.

Velez J., F.J. (1984) Madera laminada de pino patula (*Pinus patula*). Laboratorio de Productos Forestales, Universidad Nacional, Medellin, Colombia. Madera III: 4-10.

Venter, J.S.M. (1974) Sulfate pulping quality of pine sawdust. Council for Scientific and Industrial Research, Pretoria, South Africa, Special Report No. 71, 17 pp.

Vermaas, H.F. (1987) Drying curve characterization for *Pinus radiata* and *Pinus patula* for temperatures above 100°C. *Holzforschung* **41**: 389-394.

Vermaas, H.F. and Wagner, L. (1983) The influence of wet bulb depression, air velocity and density on the drying properties of *Pinus radiata* and *Pinus patula* at temperatures of 110° and 130°C respectively. In: Proceedings of the IUFRO Division V Conference, Madison, Wisconsin, July, 1983. Forest Products Laboratory, Madison, Wisconsin, USA, 175-207.

Villiers, A.M. de (1965) Silvicultural, exploitation and conversion methods that affect timber quality. Part I. *South African Forestry Journal* **55**: 21-31.

Villiers, A.M. de (1966) Silvicultural, exploitation and conversion methods that affect timber quality. Part II. *South African Forestry Journal* **56**: 5-10.

Villiers, A.M. de (1972) Present-day requirements in respect of wood properties with special reference to the deficiencies of the Forest Department. *Forestry in South Africa* **13**: 15-25.

Villiers, A.M. de (1973) Observations on the timber properties of certain tropical pines grown in South Africa and their improvement by tree breeding. In: Selection and breeding to improve some tropical conifers. (Eds. Burley, J. and Nikles, D.G.). Commonwealth Forestry Institute, Oxford, UK, and Department of Forestry, Queensland, Australia. Vol. I: 95-115.

Villiers, A.M. de (1974) Observations on the timber properties of certain tropical pines grown in South Africa and their improvement by tree breeding. *Forestry in South Africa* **15**: 57-64.

Villiers, A.M. de and Perry, N.G. (1973) The use of South African softwoods. Department of Forestry, Pretoria, South Africa, 36 pp.

Villiers, P.C. de (1970) The effect of log quality on the quality of sawn structural timber. *South African Forestry Journal* **72**: 7-11.

Villiers, P.C. de, Marsh, E.K., Sonntag, A.E. and Wyk, J.H. van (1961) The silviculture and management of exotic conifer plantations in South Africa. *Forestry in South Africa* **1**: 13-29.

Vitalis Brun, A., Vergnet, A.M. and Villenueve, F. (1990) Les tannins de pins tropicaux. In: Actes du 3e Colloque Sciences et Industries du Bois. Bordeaux, France, May, 1990. Tome I: 247-256.

Vuren, N.J.J. van, Banks, C.H. and Stohr, H.P. (1978) Shrinkage and density of timbers used in the Republic of South Africa. Department of Forestry, Pretoria, South Africa, Bulletin No. 57, 55 pp.

Wanene, A.G. (1975) A provisional yield table for *Pinus patula* grown in Kenya. Forest Department, Nairobi, Kenya, Technical Note No. 143, 24 pp.

Wayman, M. and Parekh, S.R. (1987) Hydrolysis and fermentation of African pine. *Biotechnology Letters* **9**: 445-446.

White, M.G., Kijazi, A.S., Maphole, J.E.N., Mkomwa, F.R., Ndanshau, I.G. and Klem, G.S. (1980) Strength properties and tracheid lengths in pine (*Pinus patula*) and cypress (*Cupressus lusitanica*) from the Meru Forest Project. Division of Forestry, Faculty of Agriculture, Forestry and Veterinary Science, University of Dar es Salaam, Tanzania, Record No. 15, 11 pp.

Whitesell, C.D. and LeBarron, R.K. (1976) Ensayos de pinos en Hawaii. *Turrialba* **26**: 115-120.

Wilkins, A.P. and Bamber, R.K. (1986) Dimensional change with time of green increment cores taken for growth stress measurement. *Wood and Fiber Science* **18**: 593-597.

Williams, A.L. and Bannister, M.H. (1962) Composition of gum turpentines from twenty-two species of pines grown in New Zealand. *Journal of Pharmaceutical Sciences* **51**: 970-975.

Wormald, T.J. (1975) *Pinus patula.* Commonwealth Forestry Institute, University of Oxford, UK, Tropical Forestry Paper No. 7, 172 pp.

Wright, J.A. and Malan, F.S. (1991) Variation in wood and tracheid properties of *Pinus maximinoi*, *P. pseudostrobus* and *P. patula*. *IAWA Bulletin* **12**: 467-475.

Wright, J.A. and Sluis-Cremer, H.J. (1992) Tracheid morphology, pulp and paper strength traits of *Pinus taeda* and *P. patula* at age 17 years in South Africa. *Tappi* **75**(5): 183-187.

Wright, J.A. and Wessels, A. (1992) Laboratory scale pulping of *Pinus pseudostrobus*, *P. maximinoi* and *P. patula*. *IPEF International* **2**: 39-44.

Wright, J.A. and Ladrach, W.E. (1993) Field demonstration of pine, cypress and eucalyptus poles and fence posts treated with CCA. Smurfit Carton de Colombia, Cali. Research Report.

Wyk, J.H. van (1958) Variation through the year in the mositure content of wood manufactured into furniture and joinery. *Journal of the South African Forestry Association* **30**: 40-43.

Wyk, J.H., van (1963) The importance of the moisture content of wood. *Forestry in South Africa* **2**: 1-6.

Zieroth, G. (1988) Charcoal from forest plantations and forest residues as industrial fuel. *Allgemeine-Forstzeitschrift* **45**: 1229-1232.

Zobel, B.J. (1965) Variation in specific gravity and tracheid length for several species of Mexican pine. *Silvae Genetica* **14**: 1-12.

Zobel, B. (1970) Mexican pines. In: *Genetic resources in plants: exploration and conservation.* (Eds. Frankel, O.H. and Bennet, E.). Blackwell, Oxford, UK, 375-379.

Zobel, B.J. and van Buijtenen, J.P. (1989) *Wood variation, its causes and control.* Springer Verlag, New York, USA, 363 pp.